Subcontractor Report

December 2003 • NREL/SR-560-35054

System Integration of Distributed Power for Complete Building Systems

Phase 2 Report

R. Kramer
NiSource Energy Technologies
Merrillville, Indiana

NREL

National Renewable Energy Laboratory

1617 Cole Boulevard
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Executive Summary

NiSource Energy Technologies Inc. (NET) has completed the second year of a planned 3-year effort to address research and development to significantly advance distributed power development, deployment, and integration. Its long-term goal is to design ways to extend distributed generation (DG) into the physical design and controls of buildings. The NET approach is to evaluate grid-connected and aggregated distributed power systems using technologies with dynamic optimization and control of energy use to identify regulatory, integration, and interconnection issues. In addition, DG, and specifically combined heat and power (CHP), holds promise to greatly improve energy efficiency and reduce environmental emissions. NET worked to meet these goals through advances in the implementation and control of CHP systems in end-user environments and a further understanding of electric interconnection and siting issues.

The first option year of the project included the following tasks:

- Task 4 – System Design
  Consideration of basic CHP design and building interface
- Task 5 – Interconnection
  Regulatory and institutional issues associated with interconnection
- Task 6 – System Performance
  Benchmark CHP system and grid interface performance and demonstrate currently available commercial CHP device installation

In this year:

1. Three CHP test sites were used to acquire data about the operation, reliability, interconnection issues, and performance of CHP systems and components. A paper detailing aspects of this research was prepared and presented at the Second International Conference on Distributed Generation in Stockholm, Sweden. (See Appendix H).

    - The test site in Chesterton, Indiana, provided efficiency, reliability, and operating information for a CHP system in an operating commercial business. This system consisted of a 30-kW microturbine with heat recovery, desiccant dehumidification, and control systems. Operating, power quality, optimization, and efficiency data were gathered.

    - Two test sites in Gary, Indiana, provided detailed operating data and information about the interaction of various CHP devices. Building models of both applications allowed extrapolation of the results to other operating conditions.

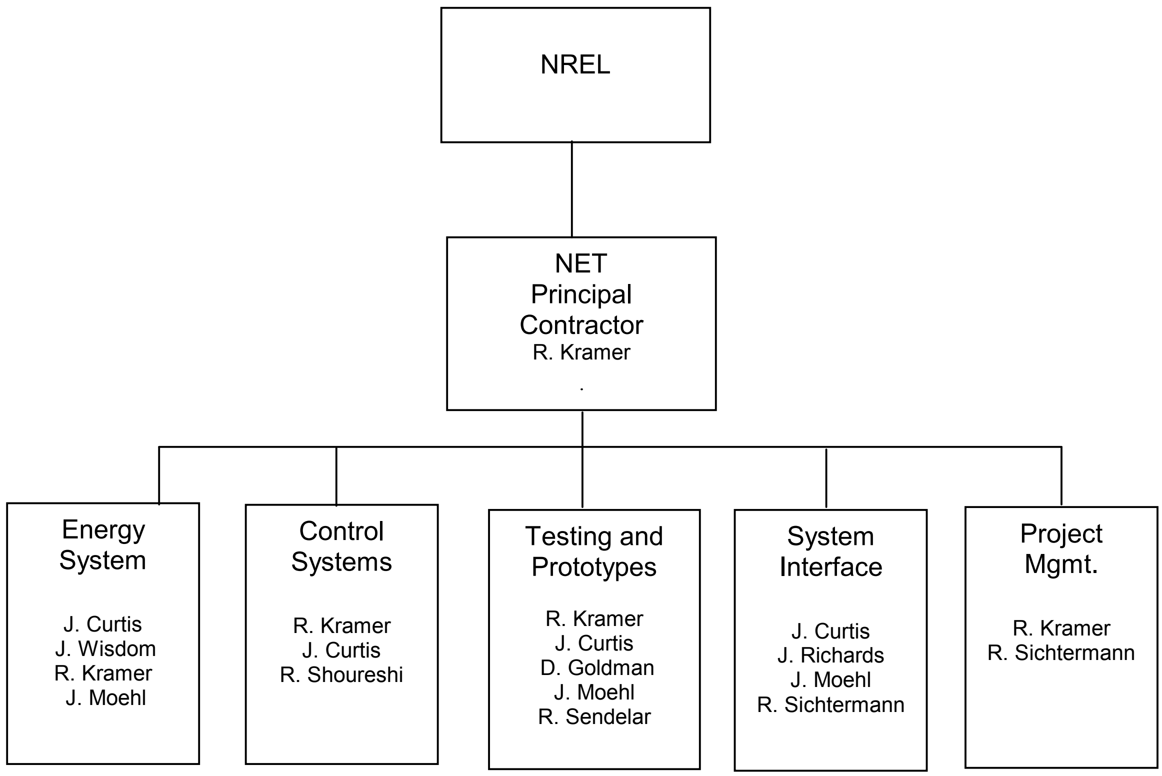
- The office site allowed consideration of the interactions of microturbines, a battery energy storage device, conventional air conditioning, CHP-driven absorption cooling, desiccant dehumidification, and an energy recovery vent.

- The warehouse site allowed consideration of the operation of a CHP system in a warehouse environment. This system consisted of a 30-kW microturbine.

2. Power quality and transient data were gathered at the Gary site for both inductive and resistive transients in grid-connected and standalone operating modes. A battery storage device was used to reshape the power waveform to compensate for the disruption caused by inductive transients. This provided valuable information about motor-starting issues.

3. A CHP demonstration site in Breeden, Indiana, provided information about the commercial installation of a CHP system. Data detailing the operation of the system and interconnection and basic startup information concerning the two 60-kW microturbines and heat recovery system were gathered.

The organizational structure for the project is shown below.



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1 Introduction

Interest in distributed generation and storage has increased substantially over the past 5 years because of its potential to provide increased reliability and lower-cost power delivery to customers. This is particularly true with customer-sited generation. The advent of competition and customer choice in the electric power industry has, in part, been the stimulus for this increased interest. Also contributing to this trend has been the development of small, modular generation technologies such as photovoltaics, microturbines, and fuel cells.

Industry estimates that distributed resources (DR) will account for up to 30% of new generation by 2010. Integrated energy systems (IES), with their high efficiency, will be an important part of this resource. The environmental benefits of distributed power (DP) exploiting, for example, renewable resources, combined heat and power (CHP), and hybrid systems are substantial.

A Department of Energy goal and vision for the 21st century is full-value DP captured in an electricity market in which customers can sell power, employ load management, and provide operations support services (ancillary services) as easily as the utility in an automated and adaptive electric power system. As the cornerstone of competition in electric power markets, DP will also serve as a key ingredient in the reliability, power quality, security, and environmental friendliness of the electric power system. By supporting customer choice, DP may be the long-term foundation of competition in the electric power industry.

Although distributed generation and storage can bring many benefits, the technologies and operational concepts to properly integrate it with the power system must be developed to avoid negative effects on system reliability and safety. The current power distribution system was not designed to accommodate active generation and storage at the distribution level or to allow such systems to supply energy to other distribution customers.

The technical issues of allowing this type of operation are significant. For example, control architectures to allow safe and reliable DP operation, and particularly to exploit the potential for DP to provide grid support, will require system protection redesign. This will require large amounts of information fed to advanced, possibly neural, networks and intelligent local controllers to act quickly to reconfigure and operate local distribution areas for local- and transmission-level benefits. New system architectures and enabling hardware and software will need to be developed.

Electricity regulation, zoning and permitting processes, and business practices developed under the framework of an industry based on central-station generation and ownership of generation facilities by a regulated monopoly can be barriers to the orderly development of market opportunities for DP in a restructured electric power industry. These barriers need to be identified and addressed through the active and mutual participation of all parties (i.e., industry and government). These parties must develop solutions and provide leadership and educational approaches to reduce infrastructure barriers to the full deployment of DP resources.

The federal government has an interest and role in the systems aspect of DP. This interest is rooted in the advent of competition in the electric industry, the reliability and security of the electric power supply and environment, and federal investments in distributed generation and storage technologies. The federal government has invested heavily in the research and development of distributed generation and storage technologies such as fuel cells, photovoltaics, wind turbines, microturbines, CHP, and batteries. It would be imprudent not to provide leadership and mission-oriented resources to address the system integration issues of these technologies in the real world, especially in light of pending deregulation and changing market and customer needs.

The system integration issues related to DP are national issues that cut across a number of industries. There is a federal leadership role to bring together these parties—hardware manufacturers (of photovoltaics, wind turbines, fuel cells, gas turbines, batteries, etc.), utilities, energy service companies, codes and standards organizations, state regulators and legislators, and others—to address the technical, institutional, and regulatory barriers to DP. In fact, these very groups have asked for assistance.

This subcontract with NiSource Energy Technologies Inc. (NET) addresses research and development to significantly advance DP development, deployment, and integration. The long-term goal is to design ways to extend distributed generation (DG) into the physical design and controls of buildings. NiSource's research and development approach is to evaluate grid-connected and aggregated DP systems using several technologies with dynamic optimization and control of energy use to identify regulatory, integration, and interconnection issues. This work will provide a foundation for solutions for a range of power users, from small industry to residences.

NET will also develop quality assurance and environmental safety and health programs in keeping with local, state, and federal regulations as applicable. This work is expected to provide societal benefits through reduced emissions.

A significant challenge of the widespread interconnection of DR with the power distribution grid is economics. DR market penetration will depend to a great extent on the cost issues of setting up of DG units to safely operate with the utility grid and the inherent reliability and power quality associated with their operation. Another critical issue is the acceptance of IES by building permitting organizations. The influence and requirements of building permitting organizations within the NiSource operating territory are considered in this work. Issues and policies that will influence the viability of IES deployment are considered and analyzed.

The specific objective of work under this subcontract is to identify the system integration and implementation issues of DG and develop and test potential solutions to these issues. In addition, recommendations are made to resolve identified issues that may hinder or slow the integration of IES into the national energy picture.

2 Task 4: System Design Results

2.1 Summary

Each DG technology has design and operational characteristics that govern its viability. The widespread use of DG in the form of IES is itself governed by a variety of factors, one of the most important being economics. One factor that greatly influences the economics of IES is its acceptance by building permitting organizations.

In this task, integrated CHP system designs and the influences and requirements of building permitting organizations within the NiSource operating territory are considered. The integration and control of a CHP system in a commercial business in Chesterton, Indiana, is modeled and benchmarked against site operating data. The control system consists of a building model, a CHP system model, and neural network and fuzzy logic techniques. Issues and policies that will influence the viability of IES deployment are considered and analyzed.

2.2 System Design and Code Issues

Building codes are generally adopted and enforced on a state-by-state basis. In several states, called *home rule states*, the local municipalities adopt and enforce building codes. A state or municipality usually will adopt one of the main national guide codes—such as the International Building Code (IBC) or the National Electrical Code (NEC)—or one of the other national guide codes. The state or municipality will also adopt amendments to that code to bring it into compliance with local tradition and law.

In general, home rule states in the NiSource service area have adopted a guide code that each municipality must use as a template when setting up its building codes. The municipality is free to amend this guide code as much as necessary, but the basic starting point is the same throughout the state. The exception to this is Maine, which has no state building code. In Maine, each municipality adopts a building code if it chooses; otherwise, only the national safety-related codes (NEC, IBC, etc.) are applied. On the other hand, some states, such as Massachusetts, start with one of the national guide codes and modify it so much that it can no longer be called a derivative of the national guide. In this case, the code is unique to that state. Massachusetts is not a home rule state, so the same rules govern everywhere in the state.

Throughout this investigation, the IBC has come into prominence in almost all nine states in the NiSource service area. It is either the standard code in use or is being phased in by 2003. The IBC deals primarily with building structural and administrative issues. Each state also adopts other codes that are implemented by reference through the administrative sections of the IBC. These codes deal with plumbing, pressure piping, pressure vessels, egress, energy efficiency, fire protection, etc.

Nationally, all states have adopted the NEC for regulating the installation of electrical equipment.

Along with the building codes adopted and amended on a statewide or local basis, most municipalities have zoning ordinances that deal with such issues as building set-backs, building height, minimum property parcel size, and noise abatement.

DG uses many technologies and, in the future, may use many more. It is difficult to predict how building codes will affect the implementation of future technologies.

The following section deals with technologies that have four properties in common:

1. The DG uses natural gas as the primary fuel source. Hydrogen could become a fuel of the future; however, at this time, building codes don't specifically address hydrogen as a common fuel source. Instead, they concentrate on natural gas and fuel oil.
2. The DG equipment may produce combustion byproducts that may cause health problems in high concentrations.
3. Electricity is the main product of the DG equipment.
4. The DG equipment also produces heat.

Because these properties affect safety and health, they are primary concerns of code enforcement officials.

Generally speaking, the NEC and the National Electrical Safety Code cover the electrical products of DG. The natural-gas piping and exhaust piping are covered in the mechanical codes of most states; however, some states cover natural gas piping in the plumbing code. For example, if the DG equipment is connected to a potable water system to heat water for washing in a CHP system, plumbing codes must also be satisfied.

A number of professional organizations set industry standards that building codes reference in their documentation. These organizations include the Institute of Electrical and Electronics Engineers (IEEE) and the American Society of Heating, Refrigerating, and Air Conditioning Engineers. By inclusion as references, some of these standards become, in effect, part of the building code.

Each year, supplements are published to update codes and deal with any enforcement problems that have been encountered. Every 3 or 4 years, new versions of codes are published. These new versions are designed to incorporate the previous supplements and improve the usability of the code.

The 2002 NEC incorporated many articles dealing with DG-related equipment such as fuel cells, generators, and solar photovoltaic systems. See articles 705, 690, and 692 for examples.

The following sections describe the building code process in each of the nine states in the NiSource service area.

2.2.1 Indiana

Indiana is not a home rule state. Residential building codes have not been adopted by the state. All commercial and industrial construction must go through the "design release" process from the state before the municipality grants a building permit. All residential building permits, however, are granted through the local municipality and do not have to be submitted to the state for a design release. Indiana uses the 1997 Unified Building Code, the 1996 International Mechanical Code, the 1997 Unified Plumbing Code, and the 1999 NEC. Indiana is in the process of adopting the 2000 IBC, which should be complete in 2003.

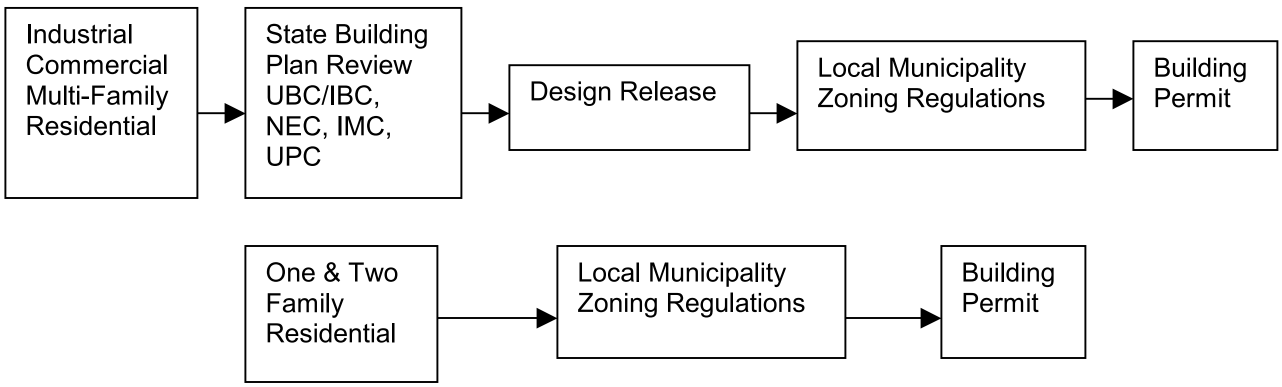


Figure 1. Indiana building code process

2.2.2 Kentucky

Kentucky is not a home rule state. If municipalities have building departments, they are state-certified; otherwise, the state has direct jurisdiction. Local building departments do not have jurisdiction over buildings more than three stories and 20,000 ft^2, state and federal buildings, health care facilities, incarceration centers, or buildings with a hazardous connotation. Kentucky uses the 2000 IBC, the 2000 NEC, the 2000 Kentucky State Plumbing Code, the 2000 International Mechanical Code, the 2000 International Electric Conservation Code, and the 2000 International Residential Code. Developers must submit design drawings to the municipality. If the municipality is not certified, it forwards the information to the state. After the state certifies the design, the municipality checks it for zoning infringements before issuing a building permit.

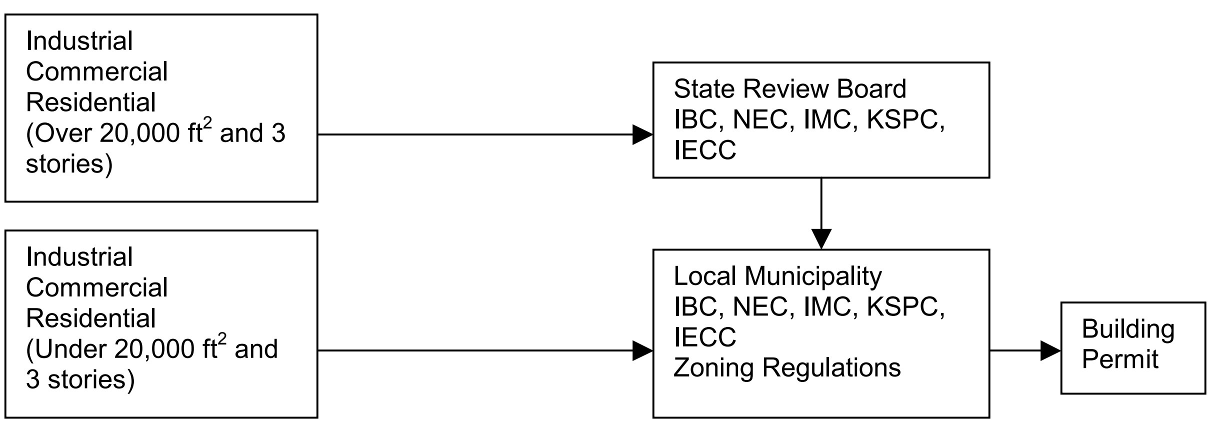


Figure 2. Kentucky building code process

2.2.3 *Maine*

Maine is a home rule state. The only state codes are the 2000 NEC, the 2002 Maine State Internal and External Plumbing Code, and the 2000 National Fire Protection Association Life Safety Code. These codes are administered by the state fire marshal's office and are not technically building codes, but they do affect construction. Maine does not use a national guide code and does not require municipalities to adopt a specific version of a national guide code. Each municipality is free to adopt its own code or not to adopt any code. The local municipality has complete jurisdiction over the installation of DG equipment.

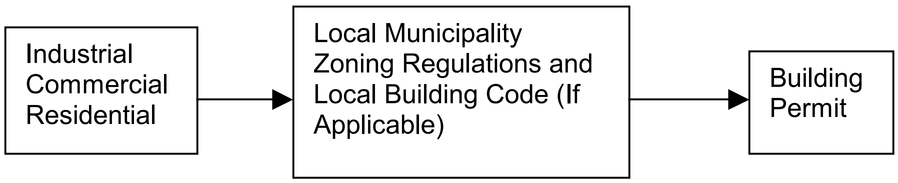


Figure 3. Maine building code process

2.2.4 *Maryland*

Maryland is a home rule state, which means that local communities have jurisdiction to amend any or all building codes. At present, all Maryland jurisdictions base their codes on the 2000 IBC, the 2000 NEC, the 2000 International Mechanical Code, and the 2000 National Plumbing Illustrated Code. These codes are the basic template that local jurisdictions adopt along with any amendments they feel necessary. These codes and local zoning regulations are then used for all construction.

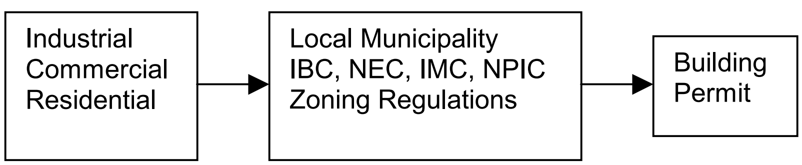


Figure 4. Maryland building code process

2.2.5 *Massachusetts*

Massachusetts is not a home rule state; however, each municipality has a state-certified building department that implements the state code and the local zoning regulations. The Massachusetts State Building Code is loosely based on the Building Officials and Code Administrators International guide code. This code has been modified to the point that all Massachusetts's codes are considered independent codes. Similarly, the electric code is a highly modified version of the NEC. The mechanical and plumbing codes also are extremely modified versions of their base international codes. Massachusetts is in the process of adopting an extremely modified version of the 2000 IBC with the 2001 and 2002 supplements. This new code will also be so modified that Massachusetts will once again not be signatory to the international building codes and will have a code considered unique.

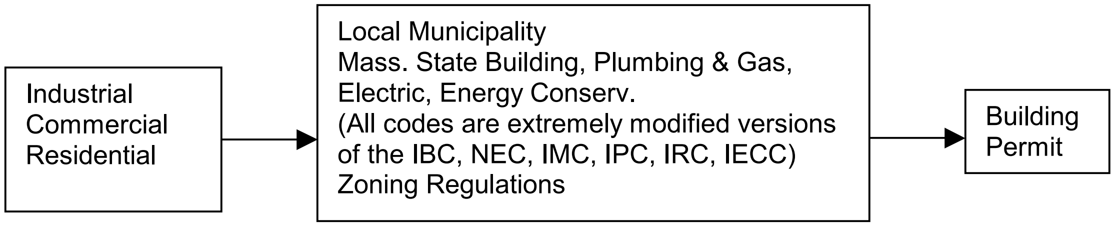


Figure 5. Massachusetts building code process

2.2.6 New Hampshire

New Hampshire is a home rule state. Local municipalities have jurisdiction to adopt amended forms of the IBC, the International Mechanical Code, the International Plumbing Code, the International Electric Conservation Code, and the NEC along with their local zoning ordinances. However, unique in this investigation, New Hampshire municipalities are free to *not* issue building permits if they so desire, and a few small jurisdictions have chosen this option. If this is the case, the developer must adhere to the above codes as adopted by the state. However *no* building permit is required. New Hampshire does not make any distinction between residential or commercial buildings. All nonindustrial construction must adhere to the commercial portions of the codes.

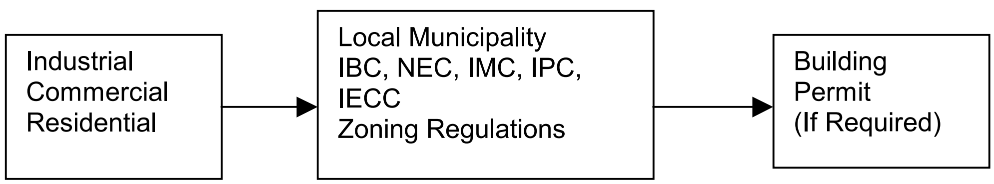


Figure 6. New Hampshire building code process

2.2.7 Ohio

Ohio is not a home rule state; however, the state certifies local building departments. If a municipality does not have a state-certified building department, then the state building department has jurisdiction. Ohio uses the 2000 IBC with 2001 supplements, the 2000 NEC, the 2000 International Plumbing Code, the 2000 International Mechanical Code, the 2000 International Electric Conservation Code, and the 2000 International Fuel Gas Code.

Developers must submit design drawings to the local municipality. If the municipality is not certified, the local municipality forwards the information to the state. After the state certifies the design, the local municipality checks the design for any zoning infringements before issuing the building permit.

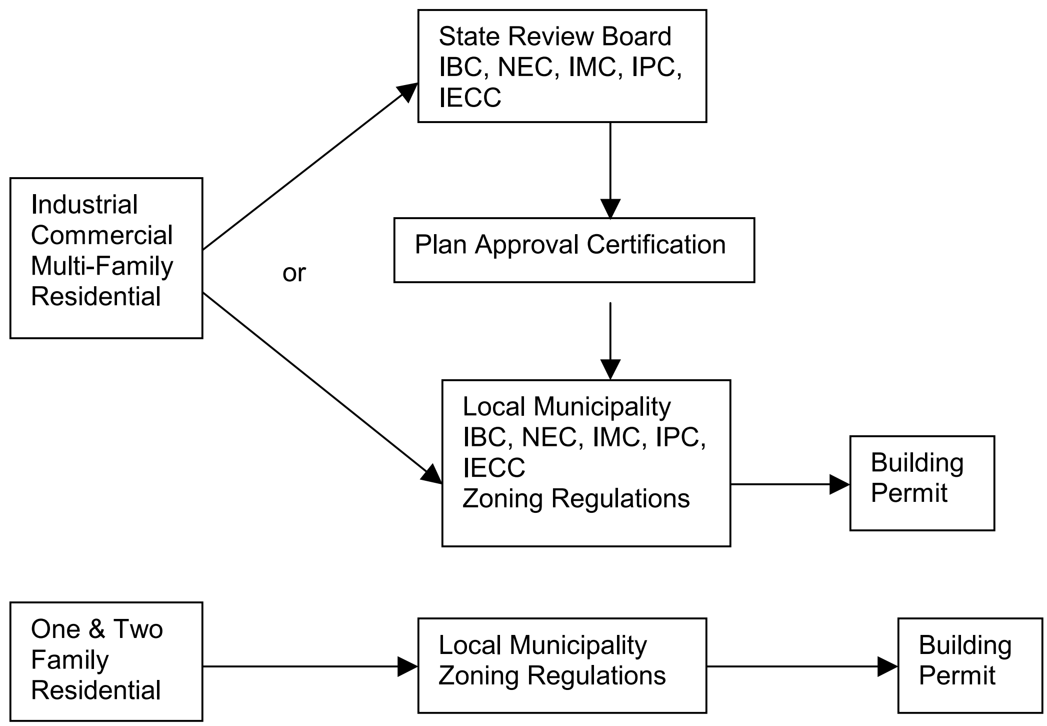


Figure 7. Ohio building code process

2.2.8 Pennsylvania

Pennsylvania uses a unique code called Title 34, Pennsylvania's Fire and Panic Code. This code has been in place and updated since 1927. In the spring of 2003, Pennsylvania will switch to a new building code. It is based on the 2000 IBC and will have Pennsylvania amendments.

A developer must submit design documents to the Department of Labor and Industry in Harrisburg. After approval from the Department of Labor and Industry, the design documents must be approved by the local jurisdiction that has the responsibility to see that the submittal meets all local zoning ordinances.

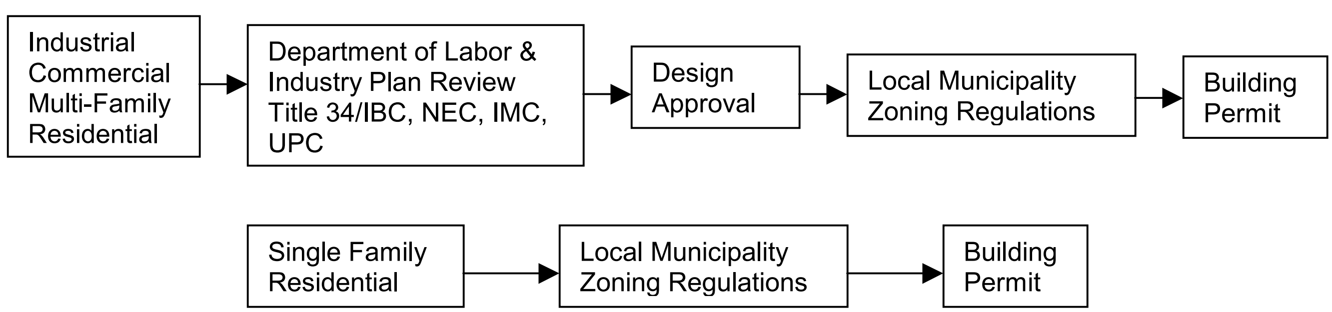


Figure 8. Pennsylvania building code process

2.2.9 *Virginia*

Virginia is a home rule state. The state is divided into jurisdictions, and each jurisdiction adopts amended versions of the codes and has its own code enforcement people and plan reviewers certified by the state. Virginia uses the 1996 Building Officials and Code Administrators building code. It is in the process of adopting the 2000 IBC. Other codes the state uses are the 1996 NEC, the 1996 International Plumbing Code, and the 1996 International Mechanical Code. Each application for a building permit must be sent to the local municipality having jurisdiction for review and permit issuance.

Figure 9. Virginia building code process

2.3 System Integrated Design and Management

An operating commercial business was selected for this portion of Task 4. This environment allows for consideration of many of the actual operating issues that future CHP systems will encounter as they become more common in the field. This site is also described in Task 6.

The Chesterton site consists of a packaged CHP system developed by NET. It includes a 30-kW microturbine; a proprietary heat recovery system; a proprietary, NET-developed desiccant dehumidification system; and a proprietary, NET-developed control system.

There were two stages of development at the Chesterton site. The first was the installation of a research test system. This was then replaced with a commercial prototype. This site has been operating for approximately 3 years.

Figure 10 shows both stages of the Chesterton site. This equipment was installed on the store roof at the request of the owner to conserve parking space.

New Refined System

Initial Test System

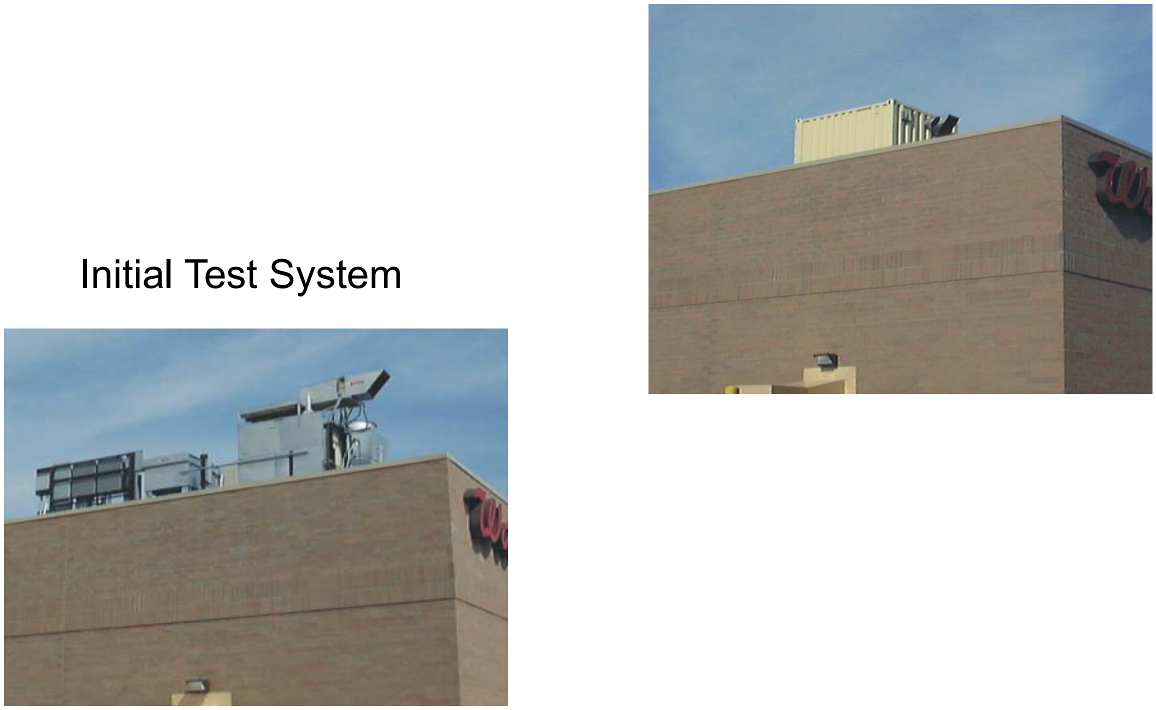


Figure 10. Chesterton site initial and current CHP systems

To successfully design a control system, a mathematical model of the system must first be developed. The complexity of a heating, ventilating, and an air conditioning (HVAC) system with distributed parameters, multiple interactions, and multiple variables makes it extremely difficult to obtain an exact mathematical model to improve control system quality. For the case of an intelligent building, the mathematical model that includes the interactions among a building, its occupants, control systems, and the external environment is complex and continuously changing.

This section of Task 4 describes a procedure for deriving a dynamic model of the HVAC system for the Chesterton site. This modeling procedure can be especially useful for control strategies that require knowledge of the dynamic characteristics of a building HVAC system.

2.3.1 HVAC System Description

Figure 11 shows a schematic diagram of the typical variable air volume system considered in this study. Because the variable air volume system is mainly a heating system, the physical model will be limited to the heating mode.

The major components of the system are:

- An air-conditioned room
- An air-handling unit
- A fan and ductwork.

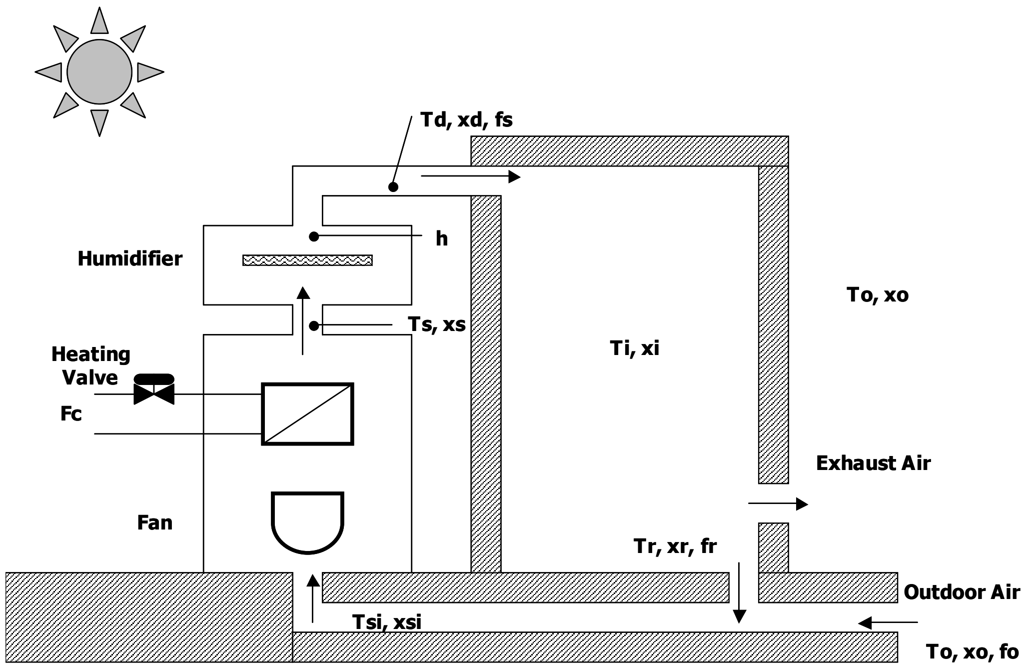


Figure 11. Typical air-handling unit

The room is connected to the air-handling unit, which consists of a heating fluid valve and a humidifier to control indoor temperature and relative humidity. Air enters the heating coil at a given temperature, which increases as the air passes through the coil. The thermometer in the downstream side of the coil senses the temperature of the air leaving the coil. Using the output from a sensor, the controller modifies the opening of a control valve. This control valve changes the hot fluid flow through the heating coils. The supply air leaving the coil enters the humidifier, which generates vapor to control indoor humidity. The hygrometer in the room senses relative humidity and feeds this information back to the controller. Using this error signal, the controller produces a controlling input as the flow rate of steam.

These control units are collectively referred to as an air-handling unit. Thus, there are three control inputs—the supply air temperature, the supply air humidity, and the airflow rate—that can be changed simultaneously in response to variable heating needs.

The outputs of interest are the temperature and relative humidity of the room. The interactions among all components must be considered so that a change of any one input can be used to influence system outputs.

2.3.1.1 Air-Handling Unit Model

For the purpose of modeling the air-handling unit, it is assumed that the unit is full of air at supply temperature and that air density is constant. The heating fluid at T_{ci} is supplied to the heating coil and returns at a temperature T_{co} to the storage tank. By identifying the energy flows to and from the air-handling unit, the energy balance can be expressed by:

$$C_a \dot{T}_s = f_c \rho_w c_w (T_{ci} - T_{co}) + \alpha_a (T_o - T_s) + f_s \rho_a c_a (T_{si} - T_s) \quad (1)$$

$$Q_{in-CHP} = f_c \rho_w c_w (T_{ci} - T_{co}) \quad (2)$$

C_a overall thermal capacitance of air-handling unit (kcal/°C)
c_a specific heat of air (0.24 kcal/kg °C)
c_w specific heat of heating water (1 kcal/kg °C)
f_c fluid flow rate through heating coil (8 x 10^{-3} m^3/min)
f_s supply airflow rate (4 m^3/min)
ρ_w density of heating water (998.2 kg/m^3)
ρ_a density of air (1.3 kg/m^3)
α_a overall transmittance-area factor outside air-handling unit (kcal/min °C)
T_s supply air temperature in air-handling unit (°C)
$\dot{T}_s$ derivative of supply air temperature in air-handling unit (°C)
T_{co} return water temperature to storage tank (°C)
T_{ci} supply water temperature to heating coil (°C)
T_o outdoor air temperature (°C)
T_{si} mixed air temperature at the inlet of air-handling unit (°C)

In Equation 1, the rate of heating energy stored in the unit is equated to the energy transferred by the heating pipe and the energy added to the unit via return air from the room and the surrounding outer surfaces of the unit. Note that two inputs, f_s (supply airflow rate) and f_c (heating fluid flow rate), appear in this equation.

The mass balance equation of the water vapor is:

$$V_a . \dot{x}_s = f_s (x_{si} - x_s) \quad (3)$$

V_a volume of air-handling unit (m^3)
x_s supply air absolute humidity in air-handling unit (kg/kg dry air)
$\dot{x}_s$ derivative of supply air absolute humidity in air-handling unit (kg/kg min dry air)
f_s supply airflow rate (4 m^3/min)
x_{si} return air absolute humidity at the inlet of air-handling unit (kg/kg dry air)

Equation 3 states that the rate of change of moisture in the unit is equal to the difference between the water vapor added to and removed from the unit. This implies that, by changing fs, the mass flow rate to the room can be varied and that water vapor can be stored in the unit.

2.3.1.2 Model of Airflow in the Duct System

The mass balance equation in the mixing (outdoor air and return air) section is:

$$f_s x_{si} = f_o x_o + f_r x_r \tag{4}$$

f_s supply airflow rate (4 m^3/min)
x_{si} return air absolute humidity at the inlet of air-handling unit (kg/kg dry air)
f_o outdoor airflow rate (1 m^3/min)
x_o outdoor air absolute humidity (kg/kg dry air)
f_r return airflow rate (1 m^3/min)
x_r return air absolute humidity (kg/kg dry air)

The corresponding model equation for the energy balance in the duct system can be described by:

$$w_{si} T_{si} = w_o T_o + w_r T_r \tag{5}$$

w_{si} product of supply airflow rate and specific heat of air at the inlet of air-handling unit (kcal/min °C)
T_{si} mixed air temperature at the inlet of air-handling unit (°C)
w_o product of outdoor airflow rate and specific heat (kcal/min °C)
T_o outdoor air temperature (°C)
w_r product of return airflow rate and specific heat (kcal/min °C)
T_r return air temperature (°C)

This model assumes that the product of airflow rate and the specific heat is in steady-state condition.

The airflow rate from outdoors is considered 25% of the total supply airflow rate. This ratio will be held constant in this study. Note that the pressure losses and the heat losses occurring in the duct are neglected for simplification.

2.3.1.3 Humidifier Model

Humidification is a requirement in some areas because of the very low humidity that exists in even a heating mode in the winter. The humidifier is the most important interface between the air-handling unit and the room. The humidifier model is separated from the air-handling unit. Because the supply air in the outlet of the unit is usually considered to be saturated vapor by heating, the relative humidity of the supply air cannot be controlled by the humidifier in the same air-handling unit. This fact is critically important to successful implementation of an air-handling unit. The energy balance of this humidifier can be expressed by:

$$C_d \dot{T}_d = w(T_s - T_d) + \alpha_a (T_o - T_d) \tag{6}$$

C_d overall thermal capacitance of humidifier (kcal/°C)
w product of supply airflow rate and specific heat of air (kcal/min °C)
α_a overall transmittance-area factor outside air-handling unit (kcal/min °C)
T_s supply air temperature in air-handling unit (°C)
T_d supply air temperature in humidifier (°C)
$\dot{T}_d$ derivative of supply air temperature in humidifier (°C)
T_o outdoor air temperature (°C)

The second term on the right is the heat gain (or loss) through the humidifier envelope, including the warm infiltration because of the inside-out temperature differential. The mass balance equation on the water vapor is:

$$V_d . \dot{x}_d = f_s (x_s - x_d) + \frac{h(t)}{\rho_a} \tag{7}$$

V_d volume of air-handling unit (m^3)
x_s supply air absolute humidity in air-handling unit (kg/kg dry air)
x_d supply air absolute humidity in humidifier (kg/kg dry air)
$\dot{x}_d$ derivative of supply air absolute humidity in humidifier (kg/kg min dry air)
f_s supply airflow rate (4 m^3/min)
ρ_a density of air (1.3 kg/m^3)
h(t) rate of moist air produced in humidifier (0.087 kg/min)

Note that in Equation 7, the rate of moist air produced in the humidifier h(t) is a function of the indoor relative humidity as one of the control inputs. When the supply air becomes saturated vapor, the input h(t) has no effect on the output $x_d(t)$.

2.3.2 Transfer Function and System Identification

Based on the obtained mathematical model and the data that were measured on the building site, system identification was performed. This process is used to find the value of each parameter in the model. The following are the transfer functions of the HVAC system and its corresponding input-output data.

2.3.2.1 Transfer Functions

Air-Handling Unit

Input:

- Qin CHP
- T_o outdoor air temperature (°C) corresponds to "DDD.oat."
- T_{si} mixed air temperature at the inlet of air-handling unit (°C)
- x_{si} return air absolute humidity at the inlet of air-handling unit (kg/kg dry air)

Output:

- T_s supply air temperature in air-handling unit (°C) corresponds to reset_sat.value."
- x_s supply air absolute humidity in air-handling unit (kg/kg dry air)

The transfer function of the air-handling unit is:

$$T_s = \left(\frac{\frac{1}{\alpha_a - f_s \rho_a c_a}}{\frac{C_a}{\alpha_a - f_s \rho_a c_a} S + 1} \right) Q_{in-CHP} + \left(\frac{\frac{\alpha_a}{\alpha_a - f_s \rho_a c_a}}{\frac{C_a}{\alpha_a - f_s \rho_a c_a} S + 1} \right) T_o + \left(\frac{\frac{f_s \rho_a c_a}{\alpha_a - f_s \rho_a c_a}}{\frac{C_a}{\alpha_a - f_s \rho_a c_a} S + 1} \right) T_{si} \tag{8}$$

$$x_s = \left(\frac{f_s}{V_a S + 1} \right) x_{si} \tag{9}$$

Here, the expression of $\alpha_a - f_s \rho_a c_a$ is always positive.

Airflow in the Duct System

Input:

- x_o outdoor air absolute humidity (kg/kg dry air)
- x_r return air absolute humidity (kg/kg dry air)
- T_o outdoor air temperature (°C)
- T_r return air temperature (°C)

Output:

- T_{si} mixed air temperature at the inlet of air-handling unit (°C)
- x_{si} return air absolute humidity at the inlet of air-handling unit (kg/kg dry air)

The transfer functions for the airflow in the duct system are:

$$x_{si} = \left(\frac{f_o}{f_s} \right) x_o + \left(\frac{f_r}{f_s} \right) x_r \tag{10}$$

$$T_{si} = \left(\frac{w_o}{w_{si}} \right) T_o + \left(\frac{w_r}{w_{si}} \right) T_r \tag{11}$$

Humidifier

Input:

- T_s supply air temperature in air-handling unit (°C)
- T_o outdoor air temperature (°C)
- x_s supply air absolute humidity in air-handling unit (kg/kg dry air)
- h(t) rate of moist air produced in humidifier (0.087 kg/min)

Output:

- T_d supply air temperature in humidifier (°C)
- x_d supply air absolute humidity in humidifier (kg/kg dry air)

The transfer functions for the humidifier system are:

$$T_d = \left(\frac{\frac{w}{w+\alpha_a}}{\frac{C_d}{w+\alpha_a} S + 1} \right) T_s + \left(\frac{\frac{\alpha_a}{w+\alpha_a}}{\frac{C_d}{w+\alpha_a} S + 1} \right) T_o \qquad (12)$$

$$x_d = \left(\frac{1}{\frac{V_d}{f_s} S + 1} \right) x_s + \left(\frac{\frac{1}{\rho_a \cdot f_s}}{\frac{V_d}{f_s} S + 1} \right) h(t) \qquad (13)$$

An HVAC model based on the energy balance and mass balance has been developed. For control design, this model was transformed into transfer function form in s-domain. Thus, the HVAC model platform was obtained. However, to apply this model for control design, the parameters need to be defined. A system identification technique will be used to perform this task. Most of the measured data that were provided are sufficient to be used in a system identification technique.

2.3.2.2 System Identification

Air-Handling Unit

$$C_a \dot{T}_s = f_c \rho_w c_w (T_{ci} - T_{co}) + \alpha_a (T_o - T_s) + f_s \rho_a c_a (T_{si} - T_s) \qquad (1)$$

$$Q_{in-CHP} = f_c \rho_w c_w (T_{ci} - T_{co}) \qquad (2)$$

$$T_s = \left(\frac{\frac{1}{\alpha_a - f_s \rho_a c_a}}{\frac{C_a}{\alpha_a - f_s \rho_a c_a} S + 1} \right) Q_{in-CHP} + \left(\frac{\frac{\alpha_a}{\alpha_a - f_s \rho_a c_a}}{\frac{C_a}{\alpha_a - f_s \rho_a c_a} S + 1} \right) T_o + \left(\frac{\frac{f_s \rho_a c_a}{\alpha_a - f_s \rho_a c_a}}{\frac{C_a}{\alpha_a - f_s \rho_a c_a} S + 1} \right) T_{si} \qquad (3)$$

C_a overall thermal capacitance of air-handling unit (kcal/°C)
c_a specific heat of air (0.24 kcal/kg °C)
c_w specific heat of heating water (1 kcal/kg °C)
f_c water flow rate through heating coil (8 x 10^{-3} m^3/min)
f_s supply airflow rate (4 m^3/min)
ρ_w density of heating water (998.2 kg/m^3)
ρ_a density of air (1.3 kg/m^3)
α_a overall transmittance-area factor outside air-handling unit (kcal/min °C)
T_s supply air temperature in air-handling unit (°C)
$\dot{T}_s$ derivative of supply air temperature in air-handling unit (°C)
T_{co} return water temperature to storage tank (°C)
T_{ci} supply water temperature to heating coil (°C)
T_o outdoor air temperature (°C)
T_{si} mixed air temperature at the inlet of air-handling unit (°C)

$$V_a.\dot{x}_s = f_s(x_{si} - x_s) \tag{4}$$

$$x_s = \left(\frac{f_s}{V_a S + 1}\right)x_{si} \tag{5}$$

V_a volume of air-handling unit (m^3)
x_s supply air absolute humidity in air-handling unit (kg/kg dry air)
$\dot{x}_s$ derivative of supply air absolute humidity in air-handling unit (kg/kg min dry air)
f_s supply airflow rate (4 m^3/min)
x_{si} return air absolute humidity at the inlet of air-handling unit (kg/kg dry air)

Airflow in the Duct System

$$f_s x_{si} = f_o x_o + f_r x_r \tag{6}$$

$$x_{si} = \left(\frac{f_o}{f_s}\right)x_o + \left(\frac{f_r}{f_s}\right)x_r \tag{7}$$

f_s supply airflow rate (4 m^3/min)
x_{si} return air absolute humidity at the inlet of air-handling unit (kg/kg dry air)
f_o outdoor airflow rate (1 m^3/min)
x_o outdoor air absolute humidity (kg/kg dry air)
f_r return airflow rate (1 m^3/min)
x_r return air absolute humidity (kg/kg dry air)

$$w_{si}T_{si} = w_oT_o + w_rT_r \tag{8}$$

$$T_{si} = \left(\frac{w_o}{w_{si}}\right)T_o + \left(\frac{w_r}{w_{si}}\right)T_r \tag{9}$$

w_{si} product of supply airflow rate and specific heat of air at the inlet of air-handling unit (kcal/min °C)
T_{si} mixed air temperature at the inlet of air-handling unit (°C)
w_o product of outdoor airflow rate and specific heat of air (kcal/min °C)
T_o outdoor air temperature (°C)
w_r product of return airflow rate and specific heat of air (kcal/min °C)
T_r return air temperature (°C)

Humidifier

$$C_d\dot{T}_d = w(T_s - T_d) + \alpha_a(T_o - T_d) \tag{10}$$

$$T_d = \left(\frac{\frac{w}{w+\alpha_a}}{\frac{C_d}{w+\alpha_a}S+1}\right)T_s + \left(\frac{\frac{\alpha_a}{w+\alpha_a}}{\frac{C_d}{w+\alpha_a}S+1}\right)T_o \tag{11}$$

C_d overall thermal capacitance of humidifier (kcal/°C)
w product of supply airflow rate and specific heat of air (kcal/min °C)
α_a overall transmittance-area factor outside air-handling unit (kcal/min °C)
T_s supply air temperature in air-handling unit (°C)
T_d supply air temperature in humidifier (°C)
$\dot{T}_d$ derivative of supply air temperature in humidifier (°C)
T_o outdoor air temperature (°C)

$$V_d.\dot{x}_d = f_s(x_s - x_d) + \frac{h(t)}{\rho_a} \tag{12}$$

$$x_d = \left(\frac{1}{\frac{V_d}{f_s}S+1}\right)x_s + \left(\frac{\frac{1}{\rho_a.f_s}}{\frac{V_d}{f_s}S+1}\right)h(t) \tag{13}$$

V_d volume of air-handling unit (m^3)
x_s supply air absolute humidity in air-handling unit (kg/kg dry air)
x_d supply air absolute humidity in humidifier (kg/kg dry air)
$\dot{x}_d$ derivative of supply air absolute humidity in humidifier (kg/kg min dry air)
f_s supply airflow rate (4 m^3/min)
ρ_a density of air (1.3 kg/m^3)
$h(t)$ rate of moist air produced in humidifier (0.087 kg/min)

2.4 Electric Load Forecasting

There is also a need to forecast the electric load as part of the energy optimization process. Electric power demand has a close correlation with weather conditions such as temperature, humidity, and sunshine. In particular, peak load demand is strongly correlated with the maximum and minimum temperatures and humidity. Therefore, to forecast peak load, it is necessary to explain the relationship between these factors.

The method used for peak load forecasting is a statistical technique typified by multiple regression analysis. However, this type of linear functional model cannot forecast accurately, and it is difficult and takes more time to develop an accurate model.

Alternatively, neural techniques have been developed. The neural network can learn the relationship between important factors from measured data. Therefore, the neural network has made more progress in application research, such as in the field of power load forecasting. In addition, fuzzy theory has been applied to power load forecasting. Fuzzy theory is a suitable method for automating imprecise knowledge and know-how of skillful human operators who can manipulate such complex systems. This report describes the peak load forecasting that will be developed to forecast the peak load of the day, the week, and the month.

2.4.1 Basic Outline for the Forecasting System

A neural network was constructed for each season. Input data consist of actual weather conditions for at least several days during the week preceding the target day, weather conditions forecast for the target day, and actual peak load data for at least several days during the week preceding the target day. Figure 12 depicts the forecasting system.

2.4.2 Daily Peak Load Forecasting System

The core of a daily peak load forecasting system is built with neural networks for next-day peak load forecasting and same-day peak load forecasting.

This system has a forecasting control module, a fuzzy inference module, a compensating yearly increase module, and the membership functions. After selecting either next-day forecasting or same-day forecasting, the forecasting is done with inputs of near actual values and the predicted weather conditions on the target day. In addition, it shows power sensitivity analysis results with respect to weather conditions.

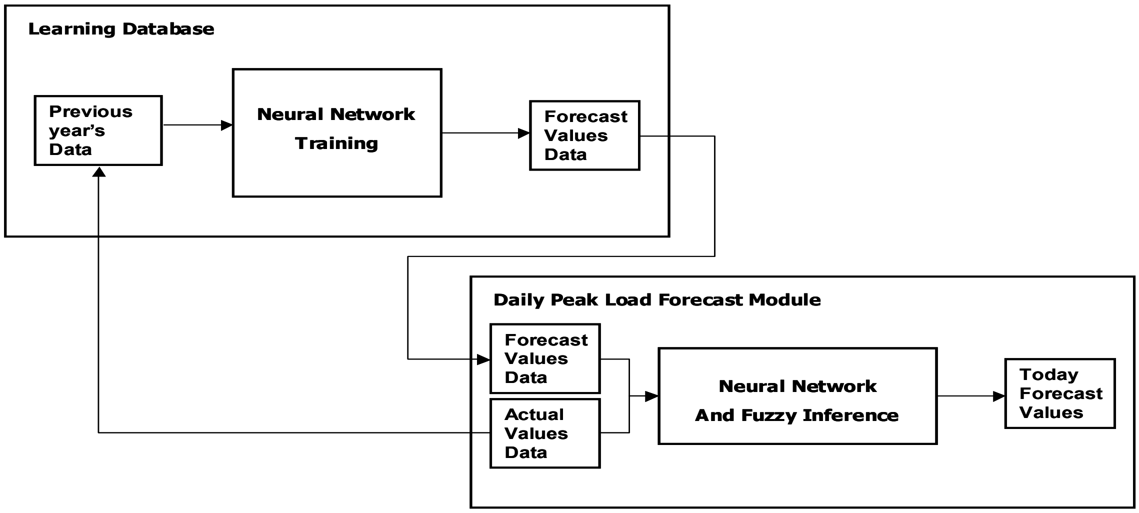


Figure 12. Configuration of the forecasting system

2.4.3 Weekly and Monthly Peak Load Forecasting System

This system carries out peak load forecasting for a week and a month. The neural network used here is a regular one that can be used for both types of forecasting. This neural network does not forecast the maximum power load of the complete week or month. It forecasts the daily peak load of each day of the concerned target week and month. The input weather conditions for weekly forecasting use next-week weather forecasts. Those for monthly forecasting use the monthly forecast.

2.4.4 Neural Network Structure

The neural network used for power peak load forecasting is built for three tasks—same-day forecasting, next-day forecasting, and weekly/monthly forecasting—for each of the four seasons. It is thereby configured from the union of 12 neural networks. These are either combined or individually selected depending on the objective and the season.

The data input to neural networks to forecast peak load are determined after considering the peak load characteristics of each season and the ease of obtaining data.

- In next-day forecasting, it is assumed that forecasting is done in the morning of the day immediately preceding the target day (i-1). Actual peak load data for that day are not available. Therefore, input peak load data for the day two days before (i-2) and for the day 7 days before (i-7) the target day are used. Actual data of weather conditions on the target day (i) are not available either. Therefore, input weather condition data for both the target day (i) and the day immediately preceding the target day (i-1) are weather forecast data.
- In same-day forecasting, when forecasting peak load on the target day, actual peak load data for the day immediately preceding the target day (i-1) are available. Therefore, input peak load data for day i-1 and day i-7 are used. Actual weather condition data for the target day (i) are weather forecast data.

- For weekly/monthly forecasting, basically average values are used because the actual weather is unknown. There are no input peak load variables because the forecasting peak load on the target days are precisely those peak loads near the forecasting period.

Table 1 shows input variables of neural networks.

Table 1. Input Variables of Neural Networks

<table>
<tr><th>Input Variables</th><th>Season</th><th>Spring</th><th>Summer</th><th>Fall</th><th>Winter</th></tr>
<tr><td>Demand</td><td>Peak Demand</td><td colspan="4">Today's Forecast: i - 1, i - 7, Next-Day Forecast: i - 2, i - 7</td></tr>
<tr><td rowspan="3">Climatic</td><td>Maximum Temp.</td><td rowspan="3">i ~ i - 2</td><td rowspan="3">i ~ i - 7</td><td rowspan="3">i ~ i - 2</td><td rowspan="2">i ~ i - 2</td></tr>
<tr><td>Minimum Temp.</td></tr>
<tr><td>Minimum Humidity</td><td>-</td></tr>
<tr><td></td><td>Weather</td><td colspan="3">-</td><td>i</td></tr>
<tr><td>Exceptional Day Flag</td><td>Saturday Flag
Holiday Flag</td><td colspan="4">i ~ i - 2</td></tr>
</table>

(Note: i indicates target day. For week and month forecasts, peak power is not used.)

2.4.4.1 Configuration of the Neural Network for Each Season

A nonlinear relationship occurs between power demand and weather conditions. Each season of the year has a different relationship between factors. Therefore, one neural network is constructed to forecast the peak load for each season.

Table 2 defines the seasonal periods. Seasonal periods were determined after considering the relationship between power demand and weather conditions, the time peak load occurred, and operational procedures. These considerations yield the following:

1. In summer, the daily peak load increases with increasing maximum temperature.
2. In winter, the daily peak load increases with decreasing maximum temperature.
3. In winter, the daily peak load occurs before noon.

The spring period is assumed to follow winter and precede summer. The autumn period is assumed to follow summer and precede winter.

Table 2. Seasonal Periods

Season	Period
Spring	April 1–June 30
Summer	July 1–Sept. 15
Fall	Sept. 16–Oct. 31
Winter	Nov. 1–March 31

2.4.4.2 Training of Neural Networks

The power load forecasting neural network is trained by a back-propagation technique. When training neural networks, it is recommended that actual data from the previous 5 years be used. These training data would be included in the database and updated every year.

The base increment of every year for each season (yearly increase) is not related to weather conditions. The peak loads of the year before the target year and those of the five years before are different because of the yearly increase in peak load in spite of similar weather conditions. For this reason, the actual peak load values of two of five years before the target year are appropriately compensated from the year before the target year and used in training.

Furthermore, some unsuitable data are included in training. This is because the actual data that might be used for training contain irregular values because of irregular weather conditions or causes other than weather conditions. Therefore, as preprocessing of neural networks training, a screening of the training data is carried out to ensure data reliability.

2.4.4.3 Application of Fuzzy Inference

There are two methods of forecasting with seasonal neural networks. One method uses a neural network for each season. This method is imperfect, however, because it is not possible to forecast accurately along season borders. For example, daily peak load cannot be forecast accurately in June, July, or September. The second method involves two neural networks that are combined to produce more accurate border forecasts. The system to forecast daily peak load can apply fuzzy inference at season borders. In June and July, the peak load for the target day is forecast by applying fuzzy inference and the spring and summer neural networks. In September, the peak load of the target day is forecast by applying fuzzy inference and the summer and autumn neural networks. Figure 13 depicts the fuzzy inference systems for border forecast.

Fuzzy inference is not applied at the winter season because it is almost always the morning peak load. The daily peak load for other seasons is almost always the afternoon peak load.

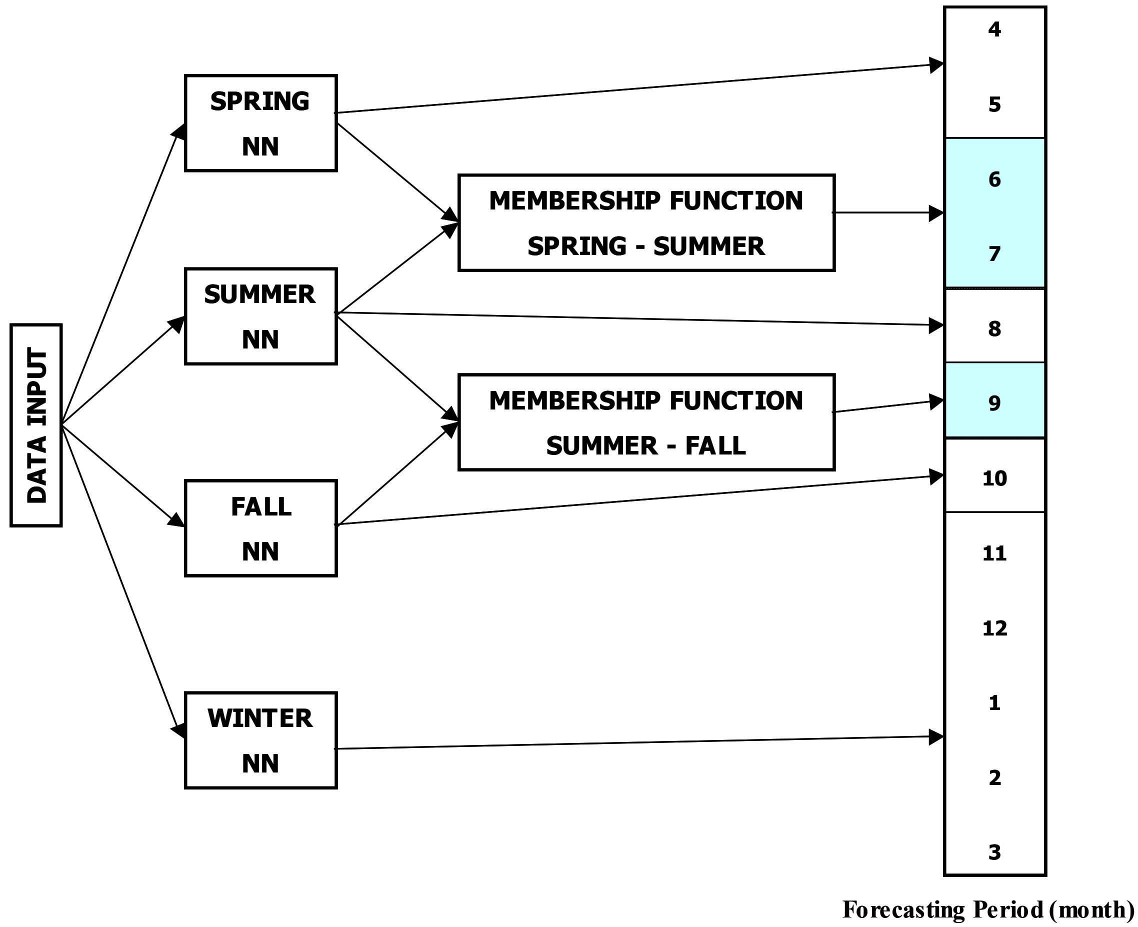


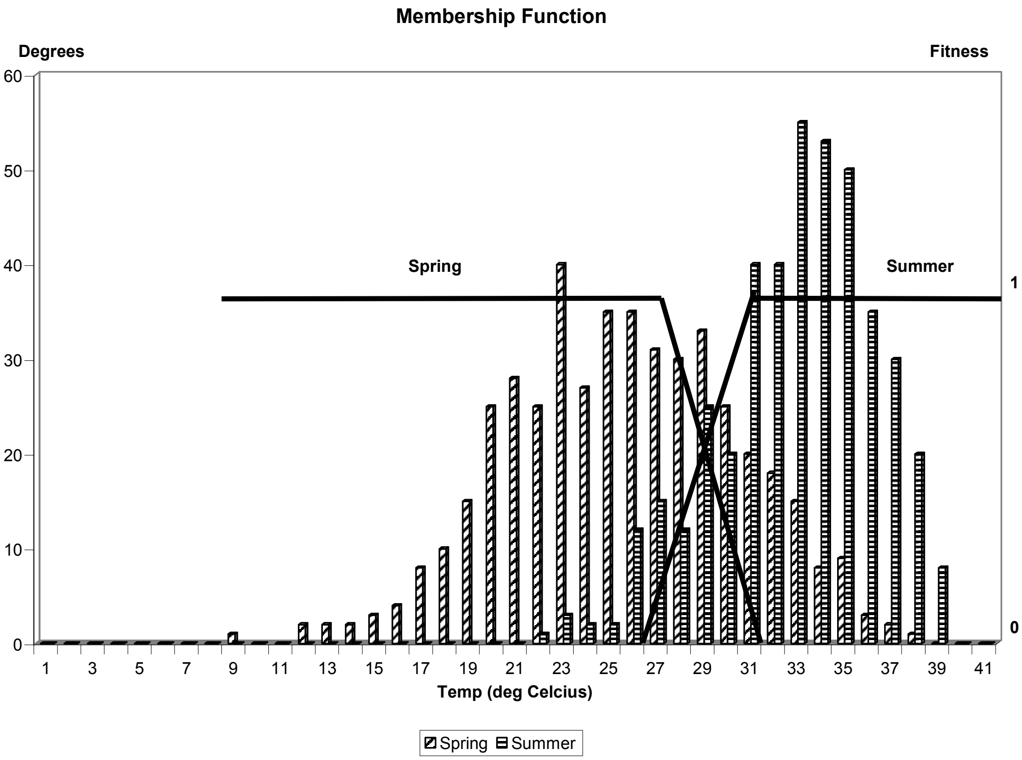
Figure 13. Membership function and neural network

2.4.4.4 Membership Functions

Determining the membership functions that express the grade of the seasons can be done by trial and error. However, a method can be developed to determine the membership function using the training data of each season network.

The membership function of the calculating grade for each season is determined by the distribution of the daily maximum temperatures of the training data.

Figure 14 shows an example of membership functions. This example shows that if the maximum temperature on the target day is higher than 26°C but lower than 31°C, then the final peak load forecast is calculated with peak load forecasts for spring and summer neural networks using fuzzy inference. These membership functions are adjusted following upgrading of training data.



(Diagonal Shade: Spring, Horizontal Shade: Summer)

Figure 14. Example of membership function

3 Task 5: Interconnection Results

3.1 Summary

A significant issue facing the widespread interconnection of DR with the power distribution grid is economics. The degree to which DR penetrate the market will depend to a great extent on the cost issues of setting up DG units to safely operate with the utility grid.

In an effort to adequately assess these cost issues, NET has considered the DR interconnection information provided by 17 investor-owned utilities.[1] This investigation concentrated on the technical and institutional costs related specifically to receiving utility permission for parallel operation. The degree of detail, classifications, and interconnection costs varied widely among these electric utilities.

A number of Rural Electric Membership Corp. (REMC) organizations were also contacted. A volume of detailed information regarding DG interconnection is available from the National Rural Electric Cooperative Association (NRECA) at its Web site (www.nreca.org).

The influence of DR manufacturers on the overall cost of interconnection was also considered. This sector directly influences the cost of interconnection through the design of equipment. NET reviewed manufacturers of reciprocating/internal combustion engines, microturbines, and fuel cells. From all indications, manufacturers have made substantial efforts to develop and produce DR equipment that facilitates safe interconnection with the grid.

3.2 Interconnection Cost Issues: Major Investor-Owned Utilities

Small-scale, customer-owned generators (microturbines, fuel cells, etc.) and their potential effect on the electric utility industry (particularly at the power distribution level) have renewed the sometimes-volatile debate over the idea of grid interconnection—only this time on a smaller scale than ever before. The Federal Energy Regulatory Commission has now issued an advanced notice of public review specifically aimed at smaller DG connection issues. This advanced notice of public review was issued in response to the detailed comments received regarding a previous notice of public review for DG in general.

Overriding issues are cost and financial responsibility. Costs incurred by the customer and the utility in the process of interconnecting with the utility grid can be separated into two categories: technical costs and institutional costs.

3.2.1 Technical Costs

Technical costs are those costs incurred by the DR owner during the interconnection process that result directly from the technical requirements[2] outlined by the controlling utility. These costs are due to the need for specialized electrical equipment arising from the following issues:

[1] These utilities are from a group of more than 100 major investor-owned utilities contacted in 2001.

[2] A detailed survey of these technical requirements was performed in 2001 and is communicated in the base year final report.

- Generator classification
  Many slightly varying approaches are taken by the 17 utilities to classify generators requesting interconnection. Among these methods are classification by size, by mode of generation, and by power flow characteristics (i.e., one-way power flow or two-way power flow).

- Electrical disconnect switch
  The disconnect switch is a mechanical device used to isolate a circuit or specific equipment from a source of power. In nearly all cases, utilities will require a disconnect device as part of the approved interconnection setup.

  The primary disconnect issues addressed by the utility standards are visible break capabilities, load break capabilities, utility accessibility and lockability, and labeling of the disconnect switch.

  With a few exceptions, consensus exists among the 17 utilities regarding the necessity of a disconnect switch between the generator and the utility and the characteristics, placement, and operability of the switch.

- Applicable codes and standards
  Another area of consideration is the referencing of various codes and standards. Nearly all reviewed utility interconnection standards require that installations meet the minimum state and local codes and requirements (in addition to the codes and standards referenced specifically in the document).

  All reviewed utility standards rely to some degree on pre-existing technical standards such as those of the American National Standards Institute (ANSI), IEEE, NEC, National Electrical Safety Code, National Fire Protection Association, and Underwriters Laboratories (UL). The most commonly referenced standards are ANSI/IEEE 519-1992, 929-2000, and C37.90; NEC; and the National Electrical Safety Code. Two particular utilities go to great lengths to reference every standard that might possibly be applicable.

- Protective relaying devices
  Protective relaying devices initiate the removal of generation equipment from service automatically and quickly when an electric fault or disturbance occurs. Proper protective relaying is essential to a safe generator-utility interconnection. In most cases, the utility requirements are solely for the protection of the utility distribution system facilities and utility personnel and do not explicitly consider protection of the generator.

Protective relaying requirements among the reviewed utilities vary in nature and complexity. Some are quite flexible—giving very little in the way of specific recommendations—while others appear to be very well defined and, in some cases, rigid. For example, a number of utilities insist that the more expensive utility-grade relays be used at the point of connection to the utility—even if the same relaying function already exists within the generator installation. However rigid the guidelines, all utilities are greatly concerned with utility system protection and employee safety.

- Isolation transformer
  A dedicated power transformer is often called for by the utility to isolate a power-producing customer from other utility customers. For example, if multiple customers—one of which possessed an interconnected power source of sufficient size—were fed off the same utility transformer, the possibility of forming an unintentional island would exist. In other words, should the utility power drop out, the independent power source could conceivably attempt to back feed power to every other customer fed off the secondary side of the same utility transformer, thereby forming an *unintentional island*. This is not a situation that utilities find desirable.

  The majority of surveyed utilities require a dedicated power transformer to isolate the generator from other utility customers.

  In the case of inverter-based systems, there is a possibility that through one particular failure mode DC current could be fed back into the installation or the surrounding distribution network. Often, an isolation transformer is required to prevent damage from this rare failure mode.

- Power quality devices
  Most of the utilities that have developed a comprehensive interconnection standard have expectations of the quality of power produced by the interconnected power source. A few of the relevant issues pertaining to power quality are voltage limits, voltage flicker, frequency control, harmonics, fault current level, and power factor.

  Generation power factor specifications are an important ingredient of any comprehensive interconnection standard. Among the utilities, a general consensus is evident regarding the issue of power quality. Most standards heavily rely on the requirements presented in IEEE 519-1992.

3.2.2 Institutional Costs

Institutional costs are the direct charges and fees developed by a utility to assist in recovering expenses it incurs over the course of the DR interconnection process. These costs, varying greatly in their details, can be divided into five classifications:

- Application costs
  The application cost is usually incurred as a result of the time initially spent by the utility processing paper work, reviewing the application for completeness, and contacting the customer to gather missing information and answer questions regarding technical and regulatory issues. This cost may also include (at the utility's discretion) a nondetailed preliminary feasibility review of the proposed installation.

- Engineering study and review costs
  When the prospective DR customer decides to proceed with the installation, the utility will likely conduct an in-depth engineering study to determine the short-term and long-term effect of the proposed interconnection on the utility's electric distribution system. In addition, this review will identify any necessary utility system modifications. The burden of this cost falls on the customer, almost without fail.

- Utility modification costs
  In many cases, modifications or additions to the utility system are necessary to safely accommodate the proposed generator installation. The customer is usually responsible for all costs associated with such modifications or additions.

- Specific technical costs
  Many of the surveyed utilities' interconnection standards contain references to costs related to purely technical issues. These go beyond the costs implied by the technical requirements outlined in detail in the 2001 base year final report. These are technical costs specifically laid out as such in the standard (i.e., they are directly referred to as "costs" in the documentation).

- Final/periodic costs
  Such costs include charges associated with the witnessing of tests, setting of relays, installation of meters, and final approval of the project site as well as possible periodic charges to cover regular future inspections, operation and maintenance procedures, etc.

3.2.3 Cost Issues in Utility Standards

This effort considered the 17 utilities described previously. Individual standards were analyzed for what appeared to be the prevailing cost-related issues addressed in utility standards as a whole: the application process, studies and reviews, utility system modifications, specific technical requirements, and final/periodic requirements.

3.2.3.1 Utility 1

- Application costs
  No mention is made in the documentation of upfront application costs.

- Engineering study and review costs
  The utility may charge for any administrative costs and costs of studies required for approval of the proposed DR interconnection.

- Utility modification costs
  Modifications to the utility distribution system configuration or protective equipment may be required (depending on the results of the study), at the customer's expense, to accommodate parallel operation. When additional facilities are required for the utility system to safely accommodate DR interconnection, the utility will install such facilities. However, the customer must reimburse the utility for costs incurred to the extent they exceed those normally incurred by the utility for nongenerating customers.

- Specific technical costs
  The following are to be designed and installed by the customer at the customer's expense: connection, transformation, switching, protective relaying, metering, and safety equipment—including a disconnect switch and all other outlined requirements.

  The installation of the following equipment may be necessary, depending on the results of the review: supervisory control and alarms, telemetering, and associated communications channels—all at the customer's expense.

  The DR customer is required, at his own expense, to provide and install meter sockets and metering cabinets in accordance with utility rules.

- Final/periodic costs
  The customer is responsible for costs related to the maintenance of the generating facility, control and protective devices, the load-break disconnect switch, and all other interconnection facilities as required to deliver power from the DR unit to the utility's system at the point of interconnection.

  Where additional easements and rights-of-way are needed, the customer is responsible for procuring property and paying necessary costs.

  The customer is required to maintain public liability and property damage insurance in the amount of $1,000,000 per occurrence.

3.2.3.2 *Utility 2*

- Application costs
  Its document contains no specific reference to an application cost.

- Engineering study and review costs
  The generating customer is responsible for any interconnection or system studies necessary to properly design and operate the interconnection.

- Utility modification costs
  DR customers may request (at their own expense) live-line reclose blocking at the utility substation.

  DR customers may also request (at their own expense) that the utility install equipment in the substation to initiate a trip signal to the generator circuit breaker when the substation breaker opens.

- Specific technical costs
  Specific technical costs are not addressed in the documentation.

- Final/periodic costs
  The DR customer will be charged for excess reactive power—the positive value by which the maximum kilovolt-amperes shall exceed 50% of the maximum kilowatts recorded during the same monthly billing period. The amount of this charge is according to current utility power factor provisions.

  Should the generator cause adverse effects to the utility system or to other utility customers, the customer bears the cost of necessary corrective action, as deemed necessary by the utility.

  Every interconnected DR installation is required to maintain liability insurance coverage with minimum limits of $1,000,000. Property damage insurance is optional.

3.2.3.3 *Utility 3*

- Application costs
  Application costs are not detailed in this utility's interconnection standard.

- Engineering study and review costs
  The document does not specifically address the cost of such studies but makes it clear that all costs incurred by both the DR customer and the utility with respect to the generator and its electrical connection to the utility system will be borne by the DR customer. This presumably includes study and review costs.

- Utility modification costs
  Any special facilities or modifications that may be required of the utility system because of the parallel operation of the DR unit will be designed and installed by the utility at the customer's expense.

- Specific technical costs
  Specific technical costs are not addressed in the standard.

- Final/periodic costs
  The utility retains operating control of the intertie device and may maintain (at the customer's expense) the intertie device, relays, and all other associated interconnection equipment for proper operation and protection of the utility primary distribution system.

  For two-way power flow installations, the utility provides bidirectional metering. A nonrefundable installation charge and a monthly charge will be assessed as indicated in the applicable rate schedule.

3.2.3.4 Utility 4

- Application costs
  The application fee is commensurate with the size of the generation and the work necessary by the utility. The amount is $200 for single-phase generators of 25 kVA or less, $300 for other generators of 100 kVA or less, and $1,000 for all generation more than 100 kVA. This fee is nonrefundable because the utility will incur these costs even if the customer abandons the project.

- Engineering study and review costs
  Utility 4 does not charge customers with generation of 100 kVA or less for this study. The exception is for single-phase generators on the secondary network, even if they are 25 kVA or less. Generation more than 100 kVA and single-phase generators on the secondary network will be quoted the full cost of study.

- Utility modification costs
  The customer is responsible for all such costs. Generally, no modifications are expected for single-phase generators of 25 kVA or less, but in exceptional cases, they might be needed.

- Specific technical costs
  Specific technical costs are not addressed in the documentation.

- Final/periodic costs
  There is a field services charge associated with the witnessing of tests, setting of relays, and installation of required metering and site approval costs for final approval to parallel with the utility grid. This charge is dependent on the size of generation and commensurate with the work necessary on the part of the utility. For single-phase generation of 25 kVA or less, there is a fixed charge of $500; for all other generation of 100 kVA or less, the fixed charge is $700. For generation more than 100 kVA, the utility will quote costs based on the size of generation and point of common coupling (PCC).

  The DR customer is required to pay an annual charge of a percentage of the capital cost of the utility's additional installation cost to cover property taxes, operation, and maintenance expenses. This annual cost is established by the appropriate tariff.

3.2.3.5 Utility 5

- Application costs
  An application deposit of $5,000 is due from each prospective DR customer prior to initiation of the study.

- Engineering study and review costs
  The document contains no specific reference to review costs; however, these costs are most likely rolled into the aforementioned $5,000 application deposit.

- Utility modification costs
  The customer is responsible for all costs incurred by the utility in relation to the connection or removal of the DR facility (which would likely include necessary system studies and modifications).

- Specific technical costs
  The customer will reimburse the utility for the installation of any additional metering equipment required by the DR unit's parallel operation. Costs related to the furnishing and installation of an electrical disconnect device are the DR customer's responsibility. Where self-excitation problems appear likely, special service arrangements may be required—at the customer's expense—to reduce the possibility of an induction generator isolating with small load. The customer may also need to install a dedicated communication link (at his own expense).

- Final/periodic costs
  The utility will maintain an electrical disconnect at the customer's expense.
  The customer is to maintain a dedicated communication link when the installation of such is necessary.

  Where protective facilities that are owned, operated, and maintained by the customer perform in a manner unacceptable to the utility, the customer will reimburse the utility for expenses incurred because of the corrective action taken.

General reference is made to the necessity of liability and property damage insurance; however, no details are given as to the level of coverage required.

3.2.3.6 Utility 6

- Application costs
  Utility documentation contains no specific reference to application costs.

- Engineering study and review costs
  When multiple inverter-derived generating facilities are connected to the same utility feeder, a detailed harmonics study may be required prior to the actual interconnection.

- Utility modification costs
  Any modifications to the utility distribution system necessitated by changes to the generating facility will be specified, purchased, and installed by the utility at the customer's expense. Likewise, any modifications required to mitigate harmonics on the utility system will be specified, purchased, and installed by the utility at the customer's expense.

- Specific technical costs
  To prevent out-of-phase reclosing, substation distribution line circuit breakers and line reclosers may have to be modified at the customer's expense—unless DR facility characteristics indicate that immediate reclosing would not be hazardous to the utility system or the generator. For interconnections to 34.5-kV delta systems, reclosing logic must be modified to include synchronism checking at the DR customer's expense.

  For all large, rotating generation facilities and certain inverter-derived facilities (those more than 10 kW), a remote terminal unit is to be purchased and installed at the customer's expense.

  Where necessary, the utility reserves the right to charge the DR customer directly for the cost of installing the dedicated transformer.

  The utility may require that electrical/Kirk key interlocks be installed at the customer's expense to prevent unsynchronized ties to other backup systems or alternate feeds to the utility system.

- Final/periodic costs
  Initial and subsequent inspection and testing of isolation and fault protection systems of the DR facility are required at the customer's expense.

3.2.3.7 Utility 7

- Application costs
  Utility 7's documentation does not specifically address application costs.

- Engineering study and review costs
  The utility will perform, at no cost to the customer, the interconnection studies necessary to determine what additions or modifications may be required to the utility system and to the customer's proposed interconnection plans.

- Utility modification costs
  The utility requires reimbursement of all costs incurred for system additions and changes required to permit parallel operation of the generating facility.

- Specific technical costs
  The documentation contains no reference to specific technical costs.

- Final/periodic costs
  Operational testing, prior to initial interconnection and at periodic intervals thereafter, will be performed by the utility. The customer will reimburse the utility for all costs.

3.2.3.8 Utility 8

- Application costs
  Based on the total project nameplate kilowatt rating, the initial feasibility analysis fee will be $100 for units less than 1 MW, $2,000 for units of 1–10 MW, and $10,000 for units more than 10 MW. This fee is applied to the initial feasibility analysis. In the event the actual costs of the initial feasibility analysis exceed this fee, the applicant will pay all additional costs.

- Engineering study and review costs
  If after the initial feasibility analysis, the applicant decides to proceed with this project, additional detailed system impact study costs, facilities costs, all interconnection costs, and any other applicable process fees will be the obligation of the applicant. If the actual initial analysis costs, system impact study costs, facilities costs, interconnection costs, and any other applicable fees are less than the initial feasibility fee, the applicant will receive a refund of the unused portion of the fee.

- Utility modification costs
  Although not addressed directly, the previous statement implies the general responsibility of the customer to finance any work on the utility system necessitated by the interconnection.

- Specific technical costs
  If the DR customer desires additional protection against the utility's reclosing with the DR unit still connected to the line, the utility will consider providing "hot line reclose blocking" at necessary points on the system. The cost of installing, maintaining, and rearranging such equipment is charged to the customer.

  The customer is required to reimburse the utility for the cost of all potential transformers, current transformers, and metering equipment. However, the utility will maintain ownership of all such equipment.

  For DR units more than 5 MVA, a leased communications line is required between the metering point and the utility's control center. In addition, a special rack of electronics furnished by the utility is required between the leased line and the metering equipment. The generating party is required to reimburse the utility for the cost of this equipment.

  If the utility installs specialized line equipment for transmission or subtransmission interconnections, the DR customer will reimburse the utility for the cost (with the utility retaining ownership of the equipment).

  Capacitor installations, where necessary, are done at the customer's expense.

- Final/periodic costs
  Occasional inspections and audits will be performed at the utility's expense, unless the results demonstrate a failure on the customer's part to comply with requirements. In such cases, the customer will incur additional expenses.

  The utility requires that the DR owner obtain and maintain general liability insurance coverage in an amount not specified in the standard. The level of coverage is subject to increases of up to, but not more than, 15% each year.

3.2.3.9 Utility 9

- Application costs
  The DR customer is responsible for all costs incurred by the utility during the application and review process. There is an application fee of $350 for units larger than 15 kVA; no fee exists for smaller units. If the applicant proceeds with a project to completion, the fee will be applied as a payment by the applicant to the utility's total interconnection cost.

- Engineering study and review costs
  A full coordinated electric system interconnection review may not be needed if aggregate generation is less than 50 kVA on a single-phase branch of a radial distribution circuit or less than 150 kVA on a single distribution feeder. The customer provides the utility with a cost-based advance payment for the review (including the coordinated electric system interconnection review) not covered by the application fee and for the utility's review of the interconnection design package.

- Utility modification costs
  Costs related to modification of the utility system are recovered from the customer. No further details are given in the provided documentation.

- Specific technical costs
  The DR customer is responsible for the cost of installing telemetering equipment for units more than 300 kVA as well as the cost of communications and monitoring systems, where necessary.

- Final/periodic costs
  The customer is invoiced for utility personnel to inspect and witness protective relay and associated equipment calibration and functional tests as well as to inspect the customer's equipment.

3.2.3.10 Utility 10

- Application costs
  No mention of such costs is made in this document.

- Engineering study and review costs
  Units more than 100 kW are subject to a case-specific review; however, the issue of costs related to such studies is not addressed.

- Utility modification costs
  The DR customer is responsible for costs incurred for any modifications to the utility's distribution system.

- Specific technical costs
  The DR customer is responsible for the cost of any nonstandard metering equipment required for the interconnection.

- Final/periodic costs
  This utility's documentation does not specifically address such costs.

3.2.3.11 Utility 11

- Application costs
  An application and initial review fee of $800 is due for prospective DR customers. No application and initial review fee exists for DR customers who qualify for net metering under state code. Fifty percent of the initial review fee will be returned should the application be rejected or retracted by the utility. Specific costs may be negotiated for nonstandard installations.

- Engineering study and review costs
  The supplemental review provides a cost estimate and schedule for the interconnection study. Payment for the supplemental review is due within 10 days after the results of the same review are provided to the applicant. A supplemental review fee of $600 is due for all DR customers with the exception of those who qualify for net metering under state code.

  When significant utility system improvements are required, the utility and the applicant enter into an agreement providing for the utility to perform additional studies, facility design, and engineering to come up with cost estimates for fixed price or actual cost billing to the applicant at the applicant's expense. After the interconnection, if actual cost billing is selected, the utility will reconcile its actual costs related to the DR facility against the application fee and any other advance payments made by the generating party. The customer will receive either a bill for balance due or a reimbursement for overpayment.

- Utility modification costs
  As implied earlier, any modifications or additions made to the utility distribution system for the sole purpose of accommodating the generating unit—whether by the utility or by an acceptable third party—are financed by the DR customer.

- Specific technical costs
  The utility only requires net generation metering to the extent that more cost effective options are not available (dependent on cost of metering relative to the need for and accuracy of data as well as the generating facility's size relative to the cost of metering).

  Bidirectional metering is required at the interconnection PCC to separately record power deliveries to and from the site. Alternatively, at the customer's cost, the utility can install multi-metering equipment to separately record power deliveries and retail purchases.

  If the DR facility is rated 1 MW or more, telemetering is required at the site at the customer's expense. For facilities interconnecting to a system operating at less than 10 kV, telemetry may be required on units more than 250 kW. Telemetering is only required to the extent that more cost-effective options are not available.

- Final/periodic costs
  If a third party performs the utility system improvements, the customer is responsible for all costs associated with the transfer of such facilities and improvements to the utility (including any income tax liability).

  The DR customer is responsible for costs reasonably incurred by the utility in maintaining interconnection facilities and distribution system improvements required solely for the interconnection.

  Should the customer choose to reserve idle interconnection facilities or distribution system improvements, the utility is entitled to continue charging for costs related to ongoing operation and maintenance of the added facilities.

  When the customer abandons added utility distribution facilities for which it has either advanced the installed costs or constructed and transferred to the utility, that customer will receive credit for net salvage value of the added facilities.

  The DR customer bears cost of operating and maintaining utility-installed metering.

3.2.3.12 Utility 12

- Application costs
  The DR customer is charged \$100 for photovoltaic systems and \$300 for nonphotovoltaic systems for application and inspection of facilities. For multiple installations of the same photovoltaic equipment covering adjacent properties and inspected in the same timeframe, the fee is reduced to \$50 per installation for the second and subsequent installations.

- Engineering study and review costs
  No specific mention is made of such costs in the utility documentation.

- Utility modification costs
  The DR customer covers all costs in excess of \$1,000 for rearranging the utility's existing distribution system facilities for parallel operation of a nonutility generator.

- Specific technical costs
  Electrical interface protection is required to monitor current, voltage, and frequency and to disconnect the power source from the utility system if these parameters exceed predetermined limits. In the case in which this protection is not integral to the DR system, the utility has the right to test the protective device system at the customer's expense.

- Final/periodic costs
  The utility has the right to inspect, at the customer's expense, installed protective device systems not integral to the power source. Installations that fail to meet requirements are subject to reinspection; the customer will be charged actual costs for this reinspection.

  The utility states that any insurance requirements for the equipment are the sole responsibility of the DR customer.

3.2.3.13 Utility 13

- Application costs
  Such costs are not specifically addressed in the standard.

- Engineering study and review costs
  Such costs are not specifically addressed in the standard.

- Utility modification costs
  Such costs are not specifically addressed in the standard.

- Specific technical costs
  Such costs are not specifically addressed in the standard.

- Final/periodic costs
  Such costs are not specifically addressed in the standard.

3.2.3.14 Utility 14

- Application costs
  The document does not specifically address such costs.

- Engineering study and review costs
  The document does not specifically address such costs.

- Utility modification costs
  The DR customer is required to contribute to any utility system modifications or additions. The nature of this contribution is determined concurrently with the service or power purchase contract according to utility policy.

- Specific technical costs
  Additional utility voltage check schemes necessary to prevent improper auto-reclosing or related modifications are to be done at the DR customer's expense.

- Final/periodic costs
  The document does not specifically address such costs.

3.2.3.15 Utility 15

- Application costs
  The application and preliminary interconnection study is free.

- Engineering study and review costs
  Payment for the utility to perform the final interconnection study is due, along with the final application, prior to the study.

- Utility modification costs
  The final study determines the complete and final costs based on the configuration agreed on by both parties. This includes details of customer contribution to the cost of modifications. The DR customer will be held responsible for the cost of modifications or additions to the utility system.

- Specific technical costs
  For customers with DR more than 5 MW, additional meters are required. The cost of such meters, telemetering equipment, communication circuits, and their installation is to be borne by the customer. The installation of special protection schemes for situations in which islanding is possible and the DR protective relaying is inadequate will be performed by the utility at the customer's expense.

  Where induction generators are to be used and the potential for self-excitation exists, the customer will be charged a one-time "capacitor charge" to cover the cost of supplying reactive current to the generator. This charge is based on 0.5 kVAR of capacitors per kilowatt of generation capacity, according to the utility's most recent average installed cost per kilovolt-ampere.

- Final/periodic costs
  Should the DR installation cause service interference for others, the customer will be required to cease operation and take corrective action at his own expense—but on the utility's time frame. The cost of operating and maintaining meters, telemetering equipment, and communication circuits is to be borne by the customer. The operation and maintenance of special protection schemes for situations in which islanding is possible and the DR protective relaying is inadequate will be performed by the utility at the customer's expense.

3.2.3.16 Utility 16

- Application costs
  The document appears to indicate that no such upfront cost is due.

- Engineering study and review costs
  If a thorough estimate of interconnection costs cannot be determined after the free initial site inspection, the utility will provide a complete estimate of interconnection costs upon the request of the customer. The cost of providing this estimate, including engineering studies where necessary, is to be covered by the customer.

- Utility modification costs
  The customer reimburses the utility for costs resulting solely from the interconnection. The cost of system improvements and equipment installed to provide retail service to the customer consistent with the utility's terms and conditions for distribution service is excluded from the cost of interconnection.

- Specific technical costs
  The document specifies customer costs related to meter equipment installation, testing, and certification. At the customer's expense, the utility may require additional relaying equipment to provide live-line blocking capability as well as rapid or automatic separation capability.

  Additional equipment (such as a remote terminal unit, communication channel, etc.) may be required at the utility's discretion.

- Final/periodic costs
  At no cost to the customer, the utility has the right to inspect and test the electrical interface at any time to certify its proper operation.

  The document also specifies a monthly charge to cover meter maintenance, reading, and billing. Testing requested by the utility as a result of malfunctioning protective equipment or accidental damage to parts of the protective system is paid for by the DR customer. In the event that the DR unit causes system disturbances, all costs associated with research and corrective action for the protective equipment will be at the customer's expense.

3.2.3.17 Utility 17

- Application costs
  The document gives no indication that such an application cost exists.

- Engineering study and review costs
  The customer pays the utility's actual costs for a feasibility study. Final costs are determined and a final bill or refund provided at the completion of the study, implying that some fee is collected prior to the study.

  The document addresses the need for additional studies in situations in which long-term parallel operation is intended. These are performed to obtain Mid-Continent Area Power Pool Design Review Committee acceptance and possibly Transmission Planning Subcommittee approval before interconnection. These bodies are independent of the utility; however, the utility offers to perform the required studies at the customer's expense.

- Utility modification costs
  The aforementioned study determines the detailed engineering design and final requirements for the interconnection to proceed and costs based on the equipment configuration determined by the customer and the utility. The customer is charged for the utility's engineering and construction labor costs; final costs are determined and a final bill or refund provided at the completion of the project.

- Specific technical costs
  The document specifies costs related to metering, telemetering, and communication circuit installation and operation, where necessary.

  Another specified cost is for protective device installation by the utility. In addition, the standard addresses programming costs necessary to incorporate generation data into the utility's energy management system.

- Final/periodic costs
  The document specifies costs related to metering/telemetering testing, maintenance, and reading in addition to inspection and testing of the entire installation.

The preceding survey takes into account only the costs specifically described and directly referred to in the documentation provided by the utility. The absence of specific costs in the above analysis in no way guarantees that such costs do not actually exist. Table 3 summarizes the above cost reference analysis.

Table 3. Summary of Interconnection Survey Results

	Application Costs	Study Costs	Modification Costs	Technical Costs	Final/Periodic Costs
Utility 1	?	√	√	√	√
Utility 2	?	√	√	?	√
Utility 3	?	?	√	?	√
Utility 4	√	√	√	?	√
Utility 5	√	?	√	√	√
Utility 6	?	√	√	√	√
Utility 7	?	√	√	?	√
Utility 8	√	√	√	√	√
Utility 9	√	√	√	√	√
Utility 10	?	√	√	√	?
Utility 11	√	√	√	√	√
Utility 12	√	?	√	√	√
Utility 13	?	?	?	?	?
Utility 14	?	?	√	√	?
Utility 15	√	√	√	√	√
Utility 16	?	√	√	√	√
Utility 17	?	√	√	√	√

3.3 Interconnection Technical and Cost Issues: REMCs

A significant movement is under way by which REMCs are being strongly encouraged to adopt some form of an interconnection standard. This idea has been put into motion by NRECA. NRECA has not only encouraged the development and adoption of DR interconnection standards among REMCs, but it has also provided very detailed and useful guidelines by which the REMCs could develop such standards—along with models for the necessary applications, contracts, etc. It is unclear to what degree NRECA's efforts have induced DR interconnection in REMC territories; however, the information and assistance it provides is detailed and should be useful.[3]

[3] This information can be found at http://www.nreca.org/leg_reg/DGToolKit/ .

Eight electric power distribution REMC organizations were considered. Each of these REMCs is apparently set up to handle DR interconnection requests strictly on a case-by-case basis. These particular organizations have not completely addressed the need to develop detailed, permanent guidelines for allowing customer generation facilities to operate in parallel with their systems. This could be due to the current lack of DR penetration in rural areas (i.e., there are probably very few customers requesting such guidelines).

To analyze the potential pitfalls of completing an interconnection with the REMC system, one needs an actual case study involving a DR interconnection.

The result of an interconnection request to this REMC, and presumably to most other REMCs at this point, is a custom document[4] that details the rules for the interconnection of DR. Apparently, the REMC leans heavily on the current draft of the IEEE 1547 interconnection standard.[5]

The following is an analysis of the documentation that is similar to the analysis performed on each of the 17 major investor-owned utilities in NET's base year report. The analysis covers all aspects of the interconnection—including technical and cost-related issues.

- Generator classification
  Mainstream utilities are taking many approaches to classifying generators requesting interconnection. Among these methods are classification by size, mode of generation, and power flow characteristics (i.e., one-way or two-way).

  Given the case-specific nature of the REMC interconnection in question, no general classification exists for DR customers. As such, the 120-kW, 480-V-or-less classification is created to accommodate this particular installation. (Only one-way power flow is allowed by the REMC in this instance.)

- Manual disconnect switch
  The disconnect switch is a mechanical device used to isolate a circuit or equipment from a source of power. In general, utilities will require such a disconnect device as part of the interconnection setup.

  This REMC's operating practices require a readily accessible, lockable, visible-break isolation device (switch) located between the REMC's pad-mounted transformer and the exterior of the building. This isolation device (switch) will isolate the main disconnect panel in the building and shall be of the same full load amperage rating and voltage rating as the main disconnect panel.

[4] The development of these guidelines required a great deal of input from the prospective DR customer.
[5] References were to IEEE 1547 Standard for Interconnecting Distributed Resources With Electric Power Systems as well as to other codes and standards referenced by it.

- Applicable codes and standards
  Another important topic is the referencing of specific codes and standards. It is important to note that nearly all utility interconnection standards require that installations meet the minimum state and local codes and requirements in addition to the codes and standards referenced specifically in the document.

  This REMC's documentation contains numerous references to IEEE 1547, NEC, and the National Electrical Safety Code.

- Protective functions and devices
  Protective relaying devices initiate the removal of equipment from service automatically and quickly when an electric fault or disturbance occurs. Proper protective relaying is essential to making a safe generator-utility interconnection. In most cases, the utility requirements are solely for the protection of the utility distribution system facilities and do not consider protection of the generator.

  This REMC requires that the DR installation be prepared to deal with the following situations (as seen at the PCC):

  - Area EPS (electric power system) faults
    The DR is to cease energizing the Area EPS for faults on the Area EPS circuit to which it is connected.

  - Area EPS reclosing coordination
    The DR is to cease energizing the Area EPS circuit to which it is connected prior to the re-energization of the PCC by the Area EPS.

  - Abnormal voltage
    When any voltage is in a range given in Table 4, the DR should cease energizing the Area EPS within the indicated clearing time.

Table 4. Interconnection System Response to Abnormal Voltages

Voltage Range (% of base voltage)	Clearing Time (seconds)
V<50	0.16
50<V<88	2.00
110<V<120	1.00
V>120	0.16

  - Abnormal frequency
    When any frequency is in a range given in Table 5, the DR should cease to energize the Area EPS within the indicated clearing time.

Table 5. Interconnection System Response to Abnormal Frequencies

Frequency Range (Hz)	Clearing Time (seconds)
>60.5	0.16
59.9–57.0 (adjustable set point)	Adjustable time delay
<57.0	0.16

- Reconnection to Area EPS
  After an Area EPS disturbance, no DR reconnection should take place until the Area EPS voltage is within Range B of ANSI C84.1 Table 1 and between 59.3 and 60.5 Hz. The DR interconnection system shall include an adjustable delay (or a fixed delay of 5 minutes) that may delay reconnection for up to 5 minutes after the Area EPS steady-state voltage and frequency are restored to the ranges identified above.

- Unintentional islanding
  For an unintentional island in which the DR energizes a portion of the Area EPS through the PCC, the DR interconnection system shall detect the island and cease to energize the Area EPS within 2 seconds of the island formation.

Factory testing of pre-packaged interconnection facilities and the protective systems of small units is acceptable. In the case of a factory test, the DG owner/operator needs to provide a written description and certification by the factory of the test, the test results, and the qualification of any independent testing laboratory. In addition, the settings of the equipment being installed are to be approved by the REMC prior to parallel operation of the DR. Interconnection testing must be approved and witnessed by the REMC.

In this particular case, what appear to be adequate factory-testing results were provided to the REMC by the owner/operator.

- Isolation transformer
  Utilities often call for a dedicated power transformer to isolate a power-producing customer from other utility customers. If multiple customers—one of which possessed an interconnected power source of sufficient size—were fed off the same utility transformer, the possibility of forming an unintentional island would exist. In other words, should the utility power drop out, the independent power source could conceivably attempt to back feed power to every other customer fed off the secondary side of the utility transformer—thereby forming an unintentional island. This is not a situation that utilities find desirable.

  In this case, the REMC did not mandate that a separate isolation transformer be installed on the customer side of the PCC. However, a dedicated, REMC-owned power transformer already existed on the customer's premises, thereby serving the purpose of isolating the DR customer from other REMC customers.

- Power quality
  Most utilities with developed, comprehensive interconnection standards have expectations of the quality of power produced by the interconnected power source. A few of the issues pertaining to power quality are voltage limits, voltage flicker, frequency control, harmonics, fault current level, and power factor.

  This REMC's interconnection requirements address the following power quality issues:

  - Limitation of DC injection
    The DR and its interconnection system shall not inject DC current greater than 0.5% of the full rated output current at the point of DR connection.

  - Limitation of flicker induced by the DR
    The DR shall not create objectionable flicker for other customers on the Area EPS.

  - Harmonics
    When the DR is serving balanced linear loads, harmonic current injection into the Area EPS at the PCC shall not exceed the limits stated in Table 6. The harmonic current injections shall be exclusive of any harmonic currents caused by harmonic voltage distortion present in the Area EPS without the DR connected.

Table 6. Maximum Harmonic Current Distortion in Percent of Current (I)

Individual Harmonic Order, h (Odd Harmonics)	h<11	11<h<17	17<h<23	23<h<35	35<h	Total Demand Distortion
Percent	4.0	2.0	1.5	0.6	0.3	5.0

I = greater of Local EPS maximum load current integrated demand (15 or 30 min.) without DR unit or the DR unit rated capacity (transformed to the PCC when a transformer exists between the DR unit and the PCC).

Even harmonics are limited to 25% of the odd harmonic limits above.

- Application costs
  No application fee was required by the REMC.

- Engineering study and review costs
  Payment for study and review were not required by the REMC in this case.

- Utility modification costs
  In this case, modifications to the REMC distribution system were not necessary. Therefore, costs of modifications were not an issue.

- Specific technical costs
  The REMC shall specify and have exclusive control of the electrical disconnect device, but the DR customer is required to purchase and install this isolation device.

  Reverse power metering shall be purchased and installed by the DR customer, but net metering and reverse power flow are prohibited.

  A telephone communication line suitable for normal data transmission shall be installed for the REMC to monitor its three-phase revenue meter and the reverse power meter.

- Final/periodic costs
  The DR customer will be required to pay for any maintenance for the electrical disconnect device. The DR customer is responsible for all costs associated with interconnection testing, commissioning, and certification procedures as specified by the REMC. Inspection tests are to be performed at least every 6 months, presumably at the DR customer's expense.

  The DR owner/operator will, at his own cost and expense, install, operate, maintain, repair, and inspect—and shall be fully responsible for—his facilities and interconnection facilities. Insurance requirements have yet to be negotiated for this project.

3.4 Interconnection Technical and Cost Issues: Distributed Resource Manufacturers

Generation equipment manufacturers play an integral role in the interconnection of DR with the utility grid. This group includes manufacturers of reciprocating/internal combustion engines, microturbines, fuel cells, and renewable power sources. These manufacturers have the ability to facilitate the interconnection effort through technology and standardization. Furthermore, equipment manufacturers could benefit significantly through increased sales and market penetration resulting from standardized interconnection methods for their customers.

This section investigates DR manufacturers and how they affect the technical and financial issues surrounding grid interconnection.

3.4.1 Reciprocating Engine Generators

The following is an assessment of the manufacturers of reciprocating engine generators.

- Manufacturer 1
  This manufacturer apparently does not offer a protective equipment package specifically designed for grid-parallel operation of DR. As such, Manufacturer 1 has not made any great effort to facilitate grid-parallel operation of its generators. Its focus is more toward backup generation than DR applications.

- Manufacturer 2
  This manufacturer offers equipment with which paralleling can be an integrated function of the generator-set control. In addition to all monitoring, protection, governing, and voltage regulation, this equipment provides all paralleling control functions, including synchronizing, load sharing, and paralleling protection plus utility paralleling functions such as import/export control and VAR/power factor control. Digital design and integration vastly improves power system reliability and performance.

- Manufacturer 3
  This manufacturer offers a dual-breaker utility-paralleling system that provides an economical method of operating one generator set parallel with a single utility source. The design allows for automatic starting, stopping, and paralleling of the generator set. The system contains the operator interface, controls, protective relays, and circuit breakers required to operate in parallel with the utility.

  If the system is running parallel with the utility and the utility fails, the utility breaker opens and the system goes into emergency/standby mode while still supplying power to the load. After utility power is restored, the generator synchronizes to the utility. When synchronized, the utility breaker closes, and the utility-paralleling system soft-unloads the generator and opens the generator breaker. Fixed-mounted electrically operated power circuit breakers are standard. Options are available for power import/export control and base load generation control.

  A microprocessor-based generator power controller contains the generator and utility intertie relaying, system logic, synchronizer, and generator load control. The generator relays include over and under voltage, over and under frequency, and reverse power; the utility intertie relays include over and under voltage, over and under frequency, reverse power, negative phase sequence current, and negative phase sequence voltage. In addition, the power controller includes an automatic synchronizer that electronically adjusts the voltage and frequency of the generator to that of the utility bus.

  If the utility requires redundant protection, an optional multifunction intertie protective relay is available with protection for phase under voltage, reverse power, phase over voltage, over and under frequency, negative sequence current, dual set point negative sequence voltage, potential transformer fuse loss detection, phase directional over current, reconnect enable, and rate of change of frequency.

3.4.2 Microturbine Engine Generators

The following is an assessment of the manufacturers of microturbine generators.

- Manufacturer 1
  This manufacturer's power conditioner is said to provide excellent waveform quality, full protection, and utility connection/disconnection as required. Flexible operating modes include utility-connected or island operation, single or paralleled multiple units, base load, peak shaving, load following, and power export options.

- Manufacturer 2
  Protective functions are built into the power conditioner, which makes external relays and contactors unnecessary. The power conditioner employs a mechanical contactor and insulate gate bipolar transistors that open and prevent export and import of power to and from the utility grid in the event of a grid disturbance. Integral protections include under and over voltage, fast over and under voltage, and over and under frequency. Passive anti-islanding protection is based on detecting and disconnecting in response to a rate of change of frequency. Reverse power flow protection, if required, can be achieved using a low-cost pulse meter in conjunction with the microturbine generator control protocols or by a conventional reverse flow protection relay.

  The power conditioner converts variable frequency AC from the high-speed permanent magnet generator to DC and then converts the DC to grid-referenced AC at 400–480 VAC, three-phase, 60 Hz. The rotating machinery is thus isolated from the utility, eliminating the need for additional equipment or operator intervention for synchronization. In grid-connected mode, the current waveform total harmonic distortion is compliant with IEEE 519 IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems. In standalone mode, voltage is supplied in the range of 150–480 VAC on each phase.

- Manufacturer 3
  This manufacturer's power conditioning system is designed to respond to abnormal voltages and, after a maximum trip time, ceases to energize the utility. The system then remains connected to the utility to sense voltage conditions for re-establishment of power to the utility. Total harmonic current distortion is to be less than 5% of the fundamental frequency current from rated inverter output to 25% of rated output. Should the utility frequency go outside the range of 59.3–60.5 Hz, the system is designed to cease energizing the utility line within 10 cycles (time delay allows ride through of short-term disturbances to avoid excessive nuisance tripping). The system should not inject DC current in excess of 0.5% of the rated inverter output current either in normal or abnormal operating conditions for any phase. Following a utility event that causes the system to cease to energize the utility line, energization remains disabled until continuous normal voltage and frequency has been maintained by the utility for 5 minutes (minimum), at which time the system energizes the utility line.

The system is designed to synchronize with the utility grid without causing voltage fluctuations at the PCC more than +/-5% of the nominal voltage. The system will not energize the utility grid unless the voltage and frequency are in the nominal acceptable range. The power conditioning system is designed to have the capability to withstand voltage and current surges in accordance with IEEE/ANSI C62.41 Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits and IEEE C37.90.1 Standard Surge Withstand Capability Tests for Protective Relays and Relay Systems.

- Manufacturer 4

  This manufacturer does offer electrical power components to facilitate grid-parallel operation. The package contains a digital protection relay. Also known as an intertie protection relay, it is designed to detect phase over and under voltage, peak (instantaneous) over voltage, over and under frequency, directional (reverse) power, negative sequence over current, negative sequence over voltage, and lockout relay functionality.

  Set points are field-adjustable for each of the protective functions to meet utility requirements. Once the fault is detected, the relay output interposing relay signals the appropriate disconnecting device (breaker, contactor, etc.) to interrupt the connection between the grid and the microturbine.

  Depending on requirements, sensing elements can be connected at the PCC or further into the facility's electrical distribution system down to the point at which the microturbine is connected. Again, depending on requirements, one protection relay can support multiple microturbine systems. The relay can be integrated into existing facility electrical enclosures. The relay is integrated into a complete installation package that includes an intertie protection relay, a test switch on the front panel, a safety relay output (provides contact multiplication), and shorting terminal blocks for sensor connection safety.

  The front-accessible test switch provides a safe means to test the intertie relay without requiring the sensing circuit to be disconnected. The safety relay acts to multiply the intertie relay's output signal to four normally open and four normally closed contacts. Each of the latter is mechanically linked and positively guided. The package enclosure is NEMA 12-rated (designed for indoor service), measures 24 in. high by 20 in. wide by 8 in. deep, and is designed for wall mounting.

  This package provides an explicit disconnect capability and over current protection for the microturbine. It includes a load break-capable, manually operated, visible break, lockable disconnect switch, which is often required for grid-parallel connection with the utility grid. A set of mechanically isolated, normally open and normally closed contacts is available to indicate the state of the switch. The package is rated for wall-mounted indoor and outdoor use so that it can serve as an externally accessible disconnect device.

Over current protection for the microturbine is provided by a set of Class R, time delay, 600-V, 150-A fuses. Each fuse is rated for 200,000-A fault current voltage-sensing points for a grid electrical protection module (intertie relay). The package is typically located within 25 ft of the facility power distribution connection.

3.4.3 Fuel Cell Generators

The following is an assessment of the manufacturers of fuel cell generators.

- Manufacturer 1

  This fuel cell's power-conditioning equipment is specially designed for DG applications. It uses an advanced anti-islanding technique that guarantees islanding detection even in a perfect islanding condition. It incorporates technology considerations specifically to address safety, reliability, and power quality concerns.

  This converter transforms different power sources, including microturbines and fuel cells, into high-quality electric power. It also provides grid-parallel operation with flexible power capacity through multi-unit operation up to eight units. When connected in parallel with the utility power grid, the conditioner real-time monitors and adjusts voltage and current outputs to the desired power level and power factor while maintaining the power quality, including the total harmonic distortion to IEEE 519 requirements. The power converter also provides a unique grid synchronization algorithm that achieves robust grid connection even under badly distorted grid conditions.

  This product offers integrated protective functions—including grid over and under voltage, grid over and under frequency, over current, and anti-islanding—to reduce the total system cost and provide a modularized product to customers.

- Manufacturer 2

  Specific technical information about this company's fuel cell system and associated power-conditioning equipment was not readily available; however, the following comments indicate significant progress on the part of the manufacturer in facilitating grid interconnection of its product.

  The California Energy Commission has certified that this manufacturer's 5-kW stationary fuel cell system complies with the requirements of the state's grid interconnection standard (Rule 21). Rule 21 streamlines otherwise complicated interconnection, operating, and metering regulations and processes applicable to DR. It also ensures safe connection to the electric grid in California while encouraging the installation of small generators to reduce the demand on the state's electrical system. This is the first fuel cell system certified under Rule 21.

Such a designation should significantly reduce the time, cost, and complexity for interconnection with California's three investor-owned electric utilities. Systems lacking this certification would have to be individually tested and certified by the utility, thereby adding cost and time to the installation process. Research indicates that this manufacturer's fuel cell system could be produced, delivered, installed, and connected within a 10-week window.

3.5 Observations

Costs incurred by the customer in the process of interconnecting with the utility grid can be separated into two categories: technical costs and institutional costs.

- In general, costs arising from utility technical requirements are a significant portion of the total cost of interconnection.

- In general, costs arising from utility institutional costs are substantial and are intended to assist the utility in recovering costs incurred throughout the interconnection process.

- The types of costs within the investor-owned utilities are application costs, study costs, system modification costs, technical costs, and final or periodic costs.

- The majority of the surveyed utilities do not present exact amounts in their standards, sometimes to the point of being vague. However, a few utilities clearly present and quantify the costs involved.

- Utility cost requirements vary substantially in degree and nature.

- Utility cost requirements, technical and institutional, pose a substantial threat to the widespread implementation of DR technologies.

- REMCs currently deal with DR interconnection requests on an individual basis.

- NRECA provides useful information and assistance to electric cooperatives that is highly relevant and applicable to DR interconnection. With its help, any REMC organization could develop a comprehensive, coherent interconnection standard.

- DR generator and generator equipment manufacturers can design capabilities into their equipment that can significantly reduce interconnection issues. There are currently varied approaches to design issues and standardized implementation.

- Major steps have been taken by the manufacturers of each of the surveyed generation technologies—reciprocating engines, microturbines, and fuel cells—to expedite the process of DR interconnection.

- Reciprocating engine manufacturers focus mainly on backup generation. However, two of the three surveyed manufacturers offer external equipment that provides convenient and safe modes of grid-parallel operation.

- Microturbine and fuel cell manufacturers are concerned primarily with the DR market. Of the manufacturers surveyed, all offer products that are thought to be "grid-ready" and require very little in the way of additional external protective equipment (contingent upon utility requirements in the particular jurisdiction).

4 Task 6: System Performance

The purpose of this task was to establish benchmark requirements for the system performance of CHP systems interfaced with the utility grid. Aspects of system performance considered include reliability, emissions, efficiency, capital and operations and maintenance costs, power quality, heat rate, conformance to IEEE standards, and control system performance. System performance was also evaluated by monitoring the performance of the power electronics interfacing with the utility grid, examining the effect of the DG on the operation of the grid and vice versa, and developing and demonstrating an on-site control system to track and control, in real time, DP interface and customer load requirements. An additional goal of Task 6 was to demonstrate the installation of a CHP system at a site in Breeden, Indiana, using commercially available CHP devices.

4.1 CHP System Benchmarks

The performance of various CHP configurations was considered at three sites. The first is a drug store in Chesterton, Indiana. The second is a small office building in Gary, Indiana, and the third is a warehouse in Gary, Indiana.

4.1.1 Chesterton Installations

As described in Task 4, this site has a packaged CHP system developed by NET that includes a 30-kW microturbine; a proprietary heat recovery system; a proprietary, NET-developed desiccant dehumidification system; and an NET-developed proprietary control system.

The Chesterton installation occurred in two stages. During Phase 1 of this contract, NET installed the initial test system. This was replaced with a commercial prototype during the second phase of the subcontract. This site has now been operating for approximately 3 years.

Figure 15 shows the stages of the development of the Chesterton site. Figure 16 shows the desiccant dehumidification unit.

New Refined System

Initial Test System

Figure 15. Chesterton site initial and current CHP systems

Figure 16. Desiccant unit

A basic outline of the CHP system is shown in Figure 17.

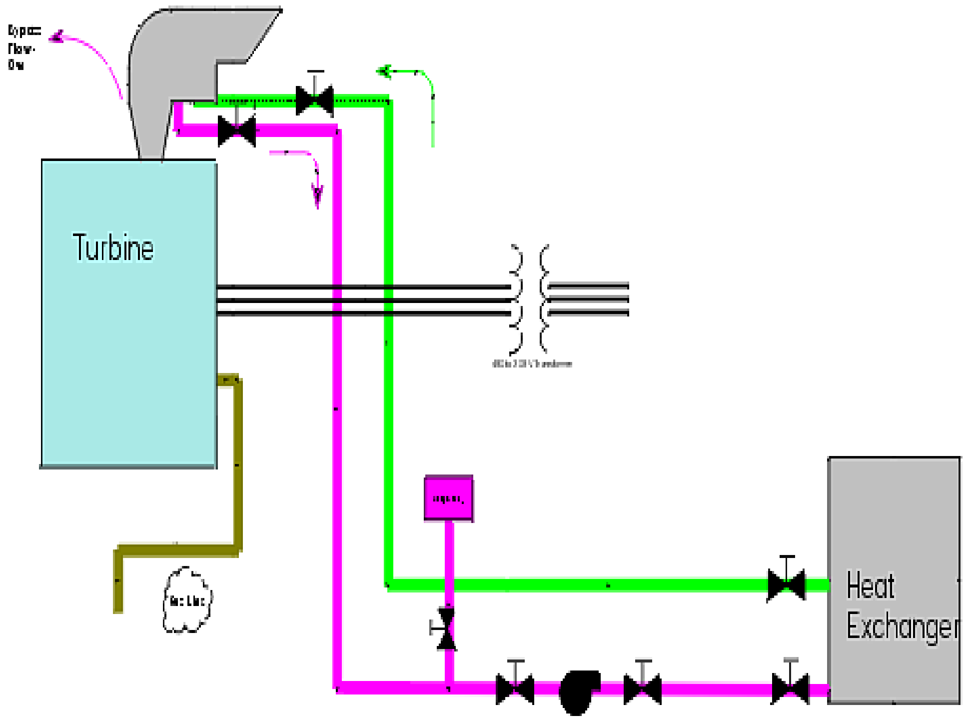


Figure 17. Heat flow diagram

In this system, a microturbine produces electricity for use in the building. Heat is recovered from the microturbine by a heat exchanger located in the exhaust gas path. Heat is transmitted from the heat exchanger by a circulating propylene glycol loop to one of two additional heat exchangers. Currently, the first additional heat exchanger provides heat for the building in winter, and the second heat exchanger provides heat for regeneration of a desiccant dehumidification system in the summer. In the future, both secondary heat exchangers may operate simultaneously depending on atmospheric conditions and building requirements.

The efficiency of the system shown in the previous figure is calculated using standard heat rate calculation as shown in Figure 18. The energy utilization figures shown take into account all losses for the system, including pumping and piping losses as well as thermal losses for the transmission of the heat. The efficiency values are thus the efficiency that the store operator experiences compared with conventional energy alternatives. This calculation was done in MathCad to provide self-documentation of each calculation during the test stage. In the future, this calculation will be rewritten into a more efficient language for production use.

Outside temp is 41.5

Data inputs

$GlycohlFlow := 7.54$ $GlycohlDilution := 46$ $PipingLoss := 1$ degrees $TurbineOut := 27906.9$ Watts $Parasitic := 4458.186$

$AveInletTemp := 165.46$ $GasMeter := 97.11041$ $GasTemp := 51.501$ $GasPres := 46.611$ $GasCost := 9.739$ \$/million btu $Gasheat := 1022$ BTU/SCF

$AveOutletTemp := 180.16$ $StandPres := 14.65$ $StandTemp := 60$ $AirFan := 4100$ Watts

$TRankine(T1) := T1 + 459.67$ $BTUperKW := 3415.179$ $GasSCFH(GM, GT, GP) := GM\cdot\left(\frac{GP + StandPres}{StandPres}\right)\left(\frac{TRankine(StandTemp)}{TRankine(GT)}\right)$

Heat Recovery Calculation

Calculate charactoristics of Propylene Glycol For various Temperatures and Dilution Factors

Specific Heat BTU/Lbm/degree

$$SpHt := \begin{pmatrix} .909 & .872 & .782 \\ .961 & .934 & .864 \\ .986 & .965 & .905 \end{pmatrix}$$

$n := rows(SpHt)$

$$X := \begin{pmatrix} 40 \\ 180 \\ 250 \end{pmatrix} \qquad Y := \begin{pmatrix} 30 \\ 40 \\ 60 \end{pmatrix}$$

$Mxy := augment(sort(X), sort(Y))$ $rows(Mxy) = 3$

Computed spline coefficients

$S := cspline(Mxy, SpHt)$

Fitting function for surface

$$SpecHeat(temp, strength) := interp\left[S, Mxy, SpHt, \begin{pmatrix} temp \\ strength \end{pmatrix}\right]$$

$SpecHeat(180, 47) = 0.911$

Density

$$Dens := \begin{pmatrix} 64.67 & 65.21 & 66.05 \\ 61.92 & 62.22 & 62.61 \\ 59.82 & 59.99 & 60.18 \end{pmatrix}$$

Computed spline coefficients $N := rows(Dens)$

$S1 := cspline(Mxy, Dens)$

Fitting function for surface

$$Density(temp, strength) := interp\left[S1, Mxy, Dens, \begin{pmatrix} temp \\ strength \end{pmatrix}\right]$$

$Density(180, 47) = 62.37$

Density is in pounds/ft cubed. one foot cubed = 7.4805190

$$GallonDensity(t2, s2) := \frac{Density(t2, s2)}{7.4805190}$$

$GallonDensity(180, 47) = 8.338$ in pounds/gallon

$$HeatInput(Flow, Tempi, Tempo, Dilution) := (SpecHeat(Tempo, Dilution)\cdot Tempo - SpecHeat(Tempi, Dilution)\cdot Tempi)\cdot 60\cdot GallonDensity(Tempo, Dilution)\cdot Flow$$

$HeatInput(GlycohlFlow, AveInletTemp, AveOutletTemp - PipingLoss, GlycohlDilution) = 5.139\times 10^{4}$ In btu/hr

$RecoveredHeat := HeatInput(GlycohlFlow, AveInletTemp, AveOutletTemp - PipingLoss, GlycohlDilution)$

Turbine Efficiencies and Heat Rate

$$\mathrm{TurbineEff}(T0, N0, G0) := T0 \cdot \frac{\mathrm{BTUperKW}}{(N0 \cdot G0 \cdot 10)}$$

$$\mathrm{TurbineHR}(T1, N1, G1) := N1 \cdot G1 \cdot \frac{1000}{T1}$$

G is btu/scfm gas heat; T turbine out in wats, and
N is Natural Gas flow in SCFH:H is recovered Heat

$$\mathrm{EffTurbineHR}(T2, N2, G2, H2) := \frac{(N2 \cdot G2 - H2)}{\left(\frac{T2}{1000}\right)}$$

$$\mathrm{OverallEff}(T3, N3, G3, H3) := \frac{\left[\left(T3 \cdot \frac{\mathrm{BTUperKW}}{1000}\right) + H3\right] \cdot 100}{N3 \cdot G3}$$

$$\mathrm{CostperKW}(GC, EFHR) := GC \cdot \frac{EFHR}{1000000}$$

Efficiency Calculation Results

$\mathrm{gasscfh} := \mathrm{GasSCFH}(\mathrm{GasMeter}, \mathrm{GasTemp}, \mathrm{GasPres})$

$\mathrm{gasscfh} = 412.832$

$\mathrm{TurbineEff}(\mathrm{TurbineOut}, \mathrm{gasscfh}, \mathrm{Gasheat}) = 22.589$

$\mathrm{TurbineHR}(\mathrm{TurbineOut}, \mathrm{gasscfh}, \mathrm{Gasheat}) = 1.512 \times 10^{4}$

$\mathrm{effhr} := \mathrm{EffTurbineHR}(\mathrm{TurbineOut} - \mathrm{Parasitic} + \mathrm{AirFan}, \mathrm{gasscfh}, \mathrm{Gasheat}, \mathrm{RecoveredHeat})$

$\mathrm{effhr} = 1.345 \times 10^{4}$

$\mathrm{OverallEff}(\mathrm{TurbineOut} - \mathrm{Parasitic} + \mathrm{AirFan}, \mathrm{gasscfh}, \mathrm{Gasheat}, \mathrm{RecoveredHeat}) = 34.479$

$\mathrm{CostperKW}(\mathrm{GasCost}, \mathrm{effhr}) = 0.131$

Figure 18. Sample heat rate calculation

Using the previous calculation procedure, the energy utilization was calculated for the Chesterton unit.

The following results are for heating for January and May of 2002. This is shown in Figure 19 and Figure 20.

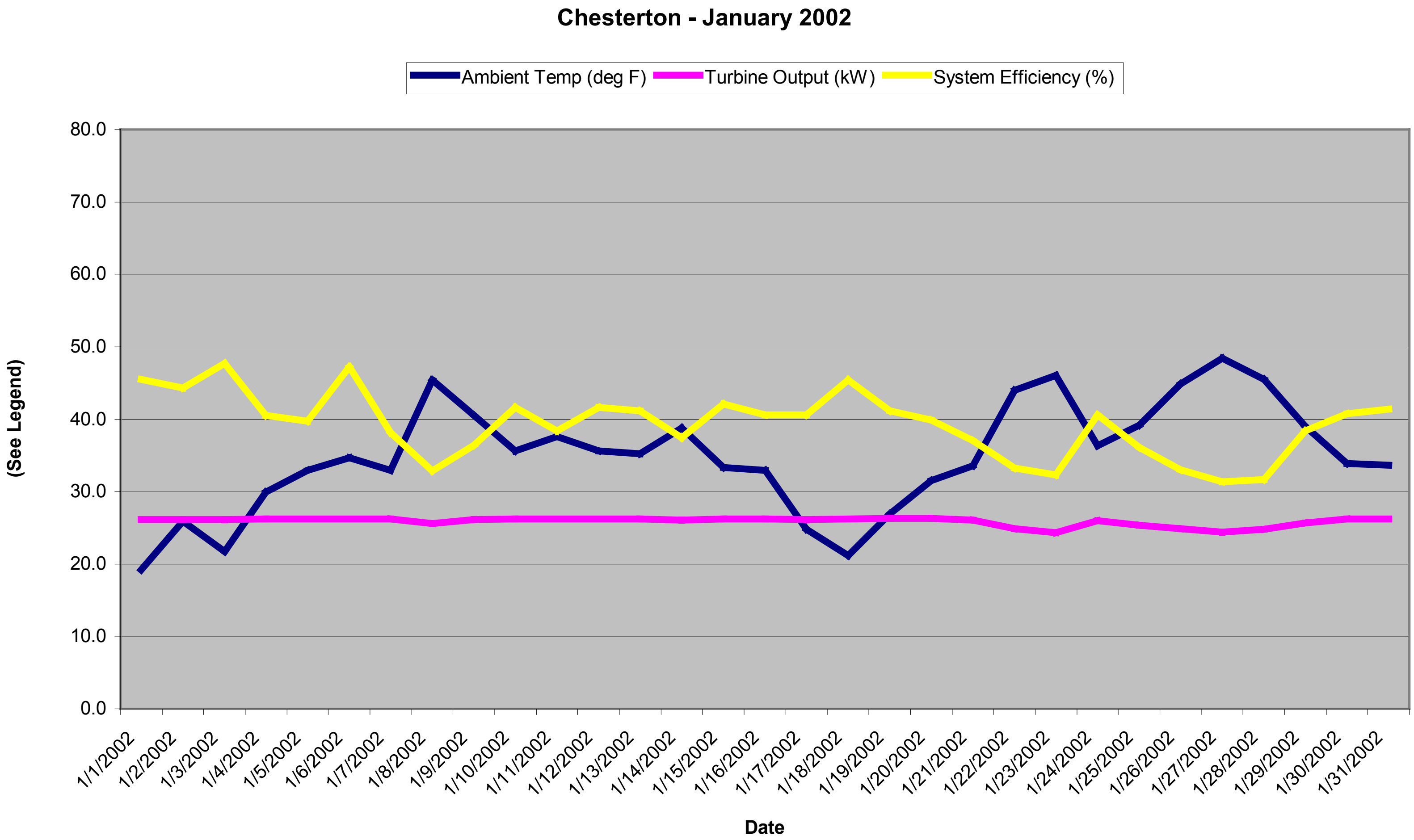


Figure 19. January 2002 Chesterton efficiency data

Table 7. January 2002 Chesterton Heat Utilizations

Date mm/dd/yy	Ambient Temp (°F)	Turbine Output (kW)	System Efficiency (%)
01/01/02	19.2	26.1	45.5
01/02/02	25.9	26.2	44.3
01/03/02	21.7	26.1	47.7
01/04/02	29.9	26.2	40.5
01/05/02	32.9	26.2	39.7
01/06/02	34.7	26.2	47.2
01/07/02	32.9	26.2	38.2
01/08/02	45.4	25.6	32.8
01/09/02	40.5	26.1	36.4
01/10/02	35.6	26.2	41.6
01/11/02	37.6	26.2	38.4
01/12/02	35.6	26.2	41.6
01/13/02	35.2	26.2	41.2
01/14/02	38.8	26.1	37.4
01/15/02	33.3	26.2	42.1
01/16/02	32.9	26.2	40.6
01/17/02	24.8	26.2	40.6
01/18/02	21.2	26.2	45.4
01/19/02	26.9	26.3	41.1
01/20/02	31.5	26.3	39.9
01/21/02	33.6	26.1	37.0
01/22/02	44.0	24.8	33.3
01/23/02	46.0	24.3	32.3
01/24/02	36.3	26.0	40.6
01/25/02	39.2	25.4	36.1
01/26/02	44.8	24.9	33.0
01/27/02	48.5	24.4	31.4
01/28/02	45.5	24.8	31.6
01/29/02	39.0	25.7	38.3
01/30/02	33.9	26.2	40.8
01/31/02	33.7	26.2	41.4

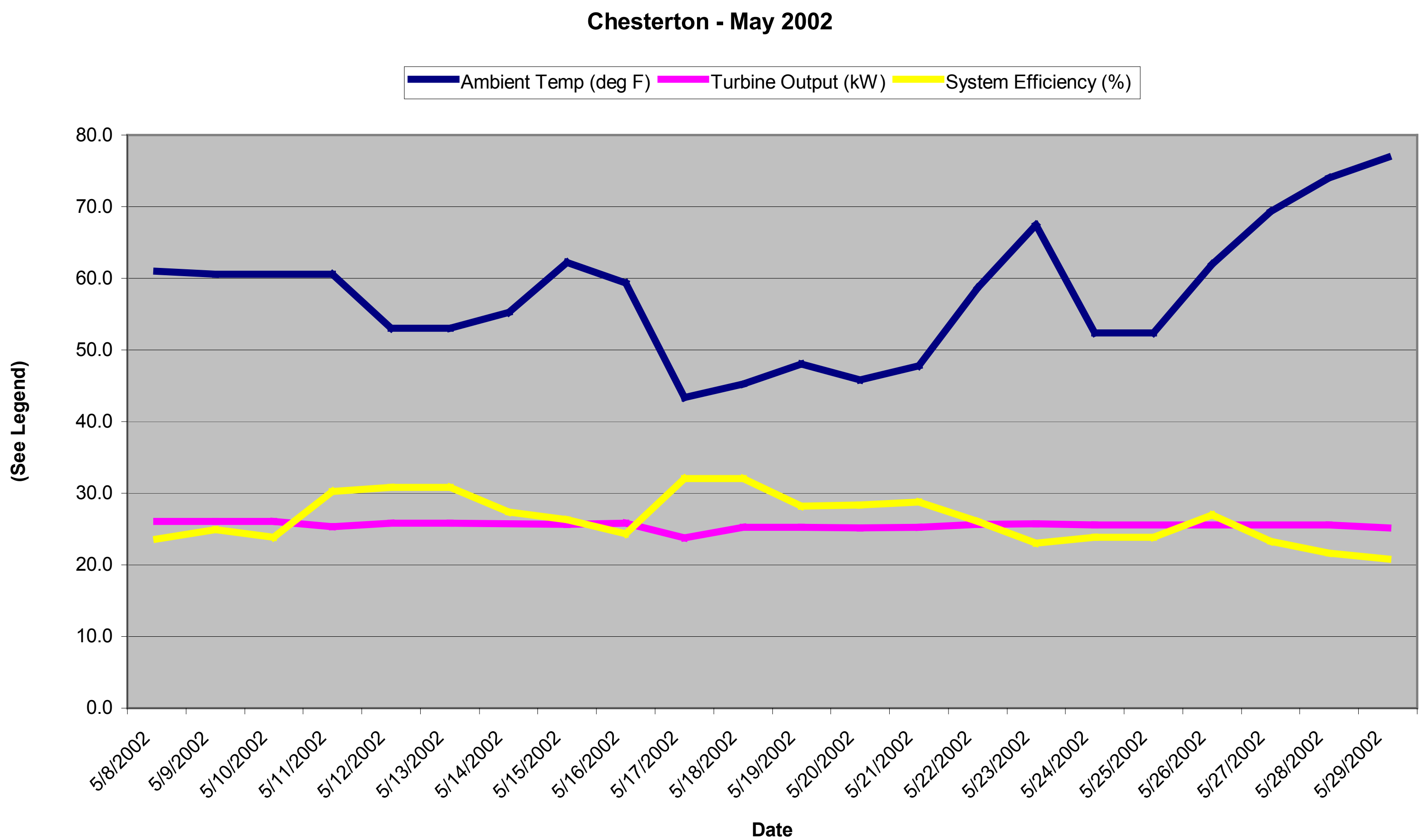


Figure 20. May 2002 Chesterton efficiency data

Table 8. May 2002 Chesterton Heat Utilizations

Date mm/dd/yy	Ambient Temp (°F)	Turbine Output (kW)	System Efficiency (%)
05/08/02	61.0	26.1	23.6
05/09/02	60.6	26.1	24.9
05/10/02	60.6	26.1	23.9
05/11/02	60.6	25.4	30.3
05/12/02	53.0	25.8	30.8
05/13/02	53.0	25.8	30.8
05/14/02	55.2	25.8	27.3
05/15/02	62.2	25.6	26.3
05/16/02	59.3	25.9	24.4
05/17/02	43.3	23.8	32.1
05/18/02	45.3	25.2	32.0
05/19/02	48.0	25.3	28.2
05/20/02	45.8	25.2	28.4
05/21/02	47.8	25.2	28.8
05/22/02	58.7	25.7	26.1
05/23/02	67.4	25.8	23.1
05/24/02	52.4	25.6	23.8
05/25/02	52.4	25.6	23.8
05/26/02	61.9	25.6	26.9
05/27/02	69.4	25.6	23.3
05/28/02	74.0	25.6	21.7
05/29/02	76.9	25.2	20.8

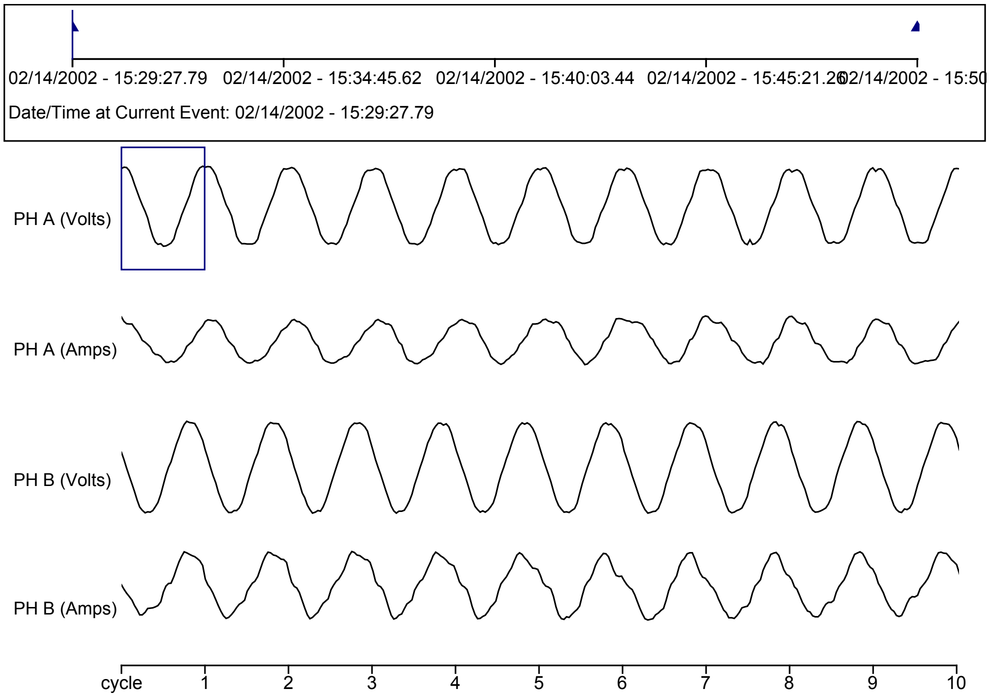
4.1.1.1 Electric Interactions Between the IES and the Grid

Issues associated with IES operation include the influence of the electric grid on the operation of the microturbine system and the operation of the IES on the microturbine. Because of the capacity of the local distribution network, the operation of a single microturbine has little influence on the operation of the grid. However, disturbances such as lightning or switching transients on the distribution network can significantly influence the operation of the inverter in the microturbine. To minimize such effects, two industrial-quality surge suppression devices were installed on the IES at the Chesterton site. One was located after the meter, and the other was on the bus feeding the control system. Two power quality devices were installed on either side of the transformer connecting the turbine to the distribution network. The two power quality monitors were synchronized, and data were gathered. This configuration allowed researchers to determine the origin of a particular disturbance as well as the direction of propagation and the general influence on power quality.

Figure 21 is an illustration of a typical waveform from the turbine side of the transformer. Figure 22 illustrates the grid side of the transformer.

A comparison of the two figures shows a switching transient attributable to weather caused a disruption on the grid side. This was attenuated as it passed through the transformer to the turbine (see Table 9). In this case, the turbine did not trip.

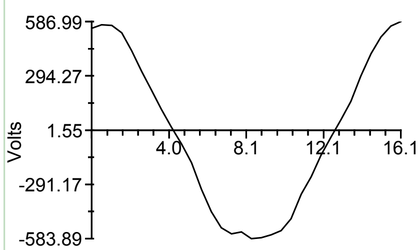
In general, reliability seems more influenced by the grid influencing the turbine than by the turbine influencing the grid. As the penetration of inverters on a particular distribution network increases, this situation may change, and the distribution network could be more influenced by the operation of the inverters. (Interactions of up to three inverters were considered in this work.)



Event: 1 Of 2
Duration: 31 Cycles

Event Trigger Input 1 PH A Volts (LOWER)
Event Trigger Cycle 1

Time:	02/14/2002 15:29:27.80
Input:	PH A Volts
Cycle:	1

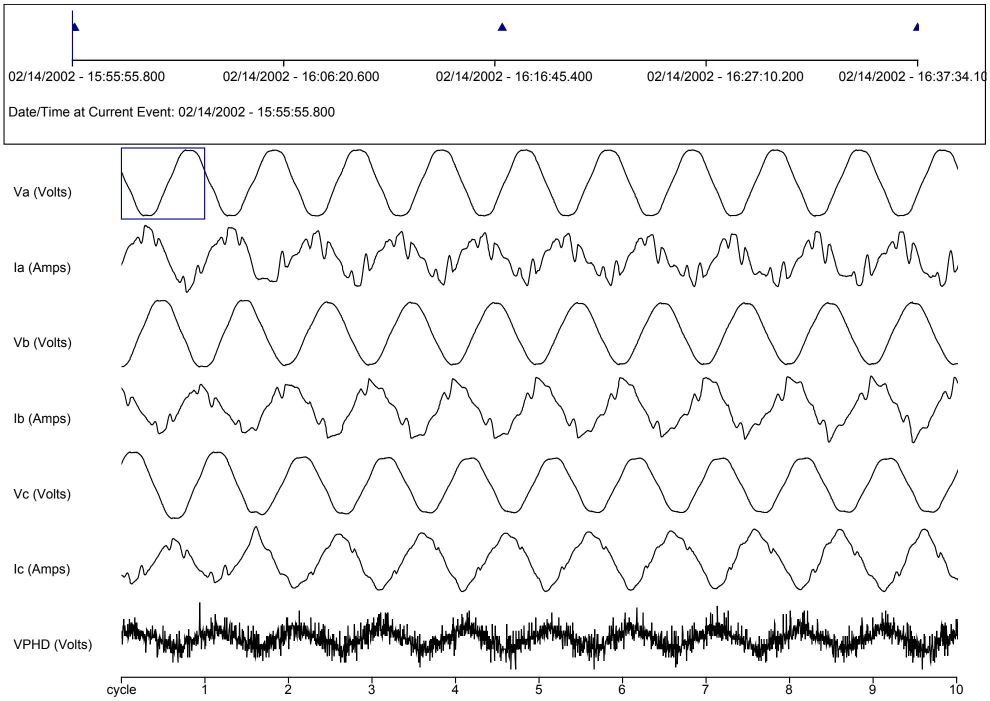


Cycle Waveform

Total Harmonic Distortion	5.48 %
Odd Contribution	5.03 %
Even Contribution	2.18 %
RMS Of Fundamental	421.46 V
RMS Of Fund + Harm	422.17 V

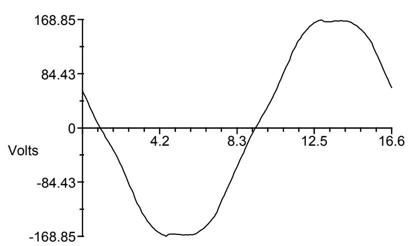
Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	421.5	0°	2	1.11	4.7	302°
3	1.15	4.9	253°	4	0.80	3.4	110°
5	4.77	20.1	192°	6	0.58	2.5	63°
7	0.47	2.0	53°	8	1.00	4.2	256°
9	0.56	2.3	84°	10	0.97	4.1	71°
11	0.66	2.8	108°	12	0.58	2.4	246°
13	0.26	1.1	257°	14	0.49	2.1	153°
15	0.43	1.8	309°				

Figure 21. Turbine side of transformer



Event: 1 Of 5
Duration: 22 Cycles
Event Trigger Input 5 Vc Volts (THD)
Event Trigger Cycle 2

Time: 02/14/2002 15:55:55.800
Input: Va Volts
Cycle: 1



Cycle Waveform

Total Harmonic Distortion	4.21 %
Odd Contribution	4.20 %
Even Contribution	0.23 %
RMS Of Fundamental	122.25 V
RMS Of Fund + Harm	122.36 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	122.3	0°	2	0.15	0.2	22°
3	0.61	0.7	155°	4	0.06	0.1	344°
5	4.08	5.0	171°	6	0.06	0.1	331°
7	0.36	0.4	63°	8	0.03	0.0	328°
9	0.19	0.2	101°	10	0.03	0.0	228°
11	0.43	0.5	60°	12	0.02	0.0	177°
13	0.29	0.4	199°	14	0.00	0.0	169°
15	0.03	0.0	156°	16	0.03	0.0	24°
17	0.17	0.2	337°	18	0.01	0.0	332°
19	0.14	0.2	170°	20	0.05	0.1	193°
21	0.10	0.1	238°	22	0.03	0.0	191°
23	0.09	0.1	195°	24	0.02	0.0	281°
25	0.13	0.2	23°	26	0.03	0.0	328°
27	0.02	0.0	305°	28	0.01	0.0	11°
29	0.09	0.1	209°	30	0.01	0.0	219°
31	0.10	0.1	268°	32	0.02	0.0	29°
33	0.08	0.1	140°	34	0.04	0.0	295°
35	0.06	0.1	77°	36	0.02	0.0	276°
37	0.04	0.1	225°	38	0.00	0.0	217°
39	0.04	0.1	265°	40	0.05	0.1	103°
41	0.05	0.1	258°	42	0.03	0.0	86°
43	0.12	0.2	132°	44	0.04	0.0	105°
45	0.03	0.0	185°	46	0.05	0.1	211°
47	0.04	0.1	275°	48	0.03	0.0	199°
49	0.06	0.1	298°	50	0.03	0.0	221°
51	0.09	0.1	160°	52	0.01	0.0	78°
53	0.06	0.1	125°	54	0.02	0.0	290°
55	0.04	0.1	280°	56	0.01	0.0	42°
57	0.01	0.0	205°	58	0.02	0.0	158°
59	0.03	0.0	155°	60	0.03	0.0	10°
61	0.03	0.0	145°	62	0.01	0.0	279°
63	0.03	0.0	327°				

Figure 22. Grid side of transformer

Table 9. Feb. 14, 2003, Turbine Data During Disturbance

Date	Time	Phase A Amps	Phase B Amps	Phase C Amps	Phase A kW	Phase B kW	Phase C kW	Total Power kW	Engine Speed	Phase A Volts	Phase B Volts	Phase C Volts
2/14/2002	0:00:00	32.996	31.989	32.996	9.421	9.165	9.316	27.955	94996	284.436	282.513	283.136
2/14/2002	0:01:00	32.996	31.989	32.996	9.432	9.182	9.344	27.966	95488	283.905	282.257	282.99
2/14/2002	0:02:00	32.996	31.989	32.996	9.429	9.174	9.333	27.971	95160	284.253	282.495	283.392
2/14/2002	0:03:00	32.996	31.989	32.996	9.456	9.201	9.344	28.015	95038	284.601	282.678	283.264
2/14/2002	0:04:00	32.996	31.989	32.996	9.443	9.163	9.349	28.043	94712	283.942	282.129	283.099
2/14/2002	0:05:00	32.996	31.989	32.996	9.462	9.218	9.338	28.109	94774	285.223	283.539	284.015
2/14/2002	0:06:00	32.996	31.989	32.996	9.467	9.185	9.344	28.026	95242	284.894	282.88	283.521
2/14/2002	0:07:00	32.996	31.989	32.996	9.432	9.174	9.336	28.026	94976	284.161	282.642	283.337
2/14/2002	0:08:00	32.996	31.989	31.989	9.456	9.185	9.344	27.955	94996	285.425	283.246	283.96
2/14/2002	0:09:00	32.996	31.989	32.996	9.413	9.174	9.327	27.933	95488	284.399	282.99	283.722
2/14/2002	0:10:00	32.996	31.989	32.996	9.456	9.207	9.347	28.07	95448	284.326	282.458	283.282
2/14/2002	0:11:00	32.996	31.989	32.996	9.456	9.201	9.363	28.01	94976	284.564	282.715	283.942
2/14/2002	0:12:00	32.996	31.989	32.996	9.459	9.187	9.352	28.109	95038	284.692	282.66	283.887
2/14/2002	0:13:00	32.996	31.989	31.989	9.454	9.163	9.33	27.96	95140	285.516	282.55	283.813
2/14/2002	0:14:00	32.996	31.989	32.996	9.451	9.165	9.325	27.982	94774	284.692	282.404	283.209
2/14/2002	0:15:00	32.996	31.989	32.996	9.44	9.165	9.316	27.966	95284	284.674	282.77	283.612
2/14/2002	0:16:00	32.996	31.989	32.996	9.456	9.179	9.325	27.982	95078	285.406	283.264	283.923
2/14/2002	0:17:00	32.996	31.989	31.989	9.44	9.196	9.341	27.977	95160	285.315	283.099	283.96
2/14/2002	0:18:00	32.996	31.989	31.989	9.443	9.196	9.344	27.966	95530	285.297	283.246	284.052
2/14/2002	0:19:00	32.996	31.989	31.989	9.424	9.16	9.311	27.916	94712	284.747	282.788	283.63
2/14/2002	0:20:00	32.996	31.989	31.989	9.451	9.198	9.341	27.933	94874	284.949	283.539	283.978
2/14/2002	0:21:00	32.996	31.989	31.989	9.44	9.171	9.319	27.966	94774	285.04	283.228	283.997
2/14/2002	0:22:00	32.996	31.989	32.996	9.47	9.201	9.363	27.988	95304	284.583	282.642	283.356
2/14/2002	0:23:00	32.996	31.989	31.989	9.456	9.176	9.333	27.982	94996	285.278	283.301	283.96
2/14/2002	0:24:00	32.996	31.989	32.996	9.426	9.154	9.316	27.993	95018	284.857	283.136	283.777
2/14/2002	0:25:00	32.996	31.989	32.996	9.489	9.196	9.344	28.037	95078	285.608	283.759	284.015
2/14/2002	0:26:00	32.996	31.989	31.989	9.413	9.16	9.303	27.905	94936	285.791	283.887	284.198
2/14/2002	0:27:00	32.996	31.989	31.989	9.429	9.182	9.319	27.96	94956	285.26	283.832	284.18
2/14/2002	0:28:00	32.996	31.989	32.996	9.462	9.223	9.358	28.098	94774	285.26	284.271	284.253

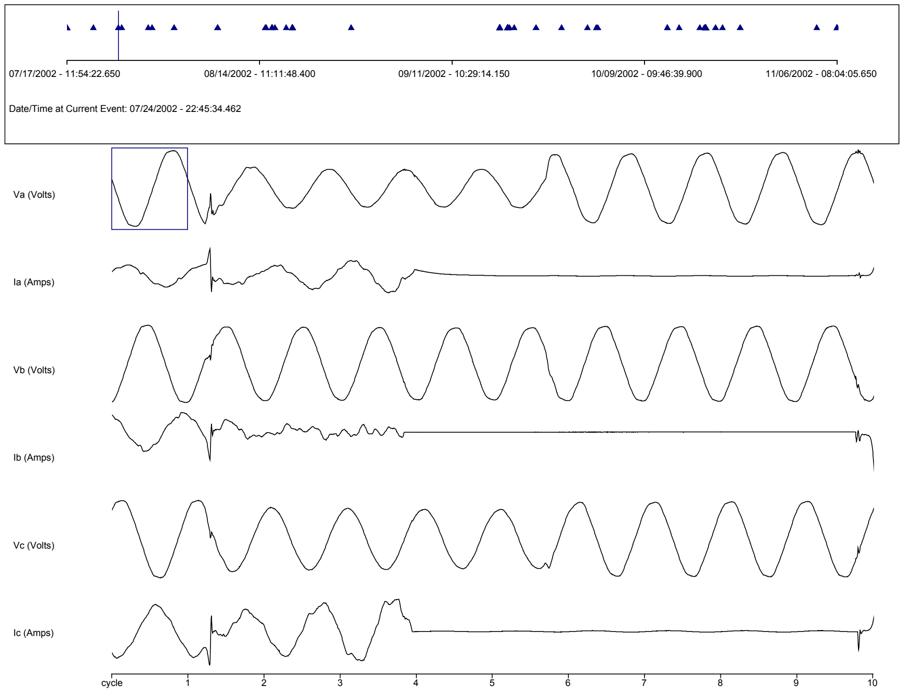
Date	Time	Phase A Amps	Phase B Amps	Phase C Amps	Phase A kW	Phase B kW	Phase C kW	Total Power kW	Engine Speed	Phase A Volts	Phase B Volts	Phase C Volts
2/14/2002	0:29:00	32.996	31.989	32.996	9.448	9.201	9.338	27.988	95078	284.601	283.154	283.557
2/14/2002	0:30:00	32.996	31.989	31.989	9.413	9.176	9.333	27.949	94732	284.985	284.015	284.93
2/14/2002	0:31:00	32.996	31.989	32.996	9.435	9.193	9.344	27.977	95448	285.205	283.502	284.473
2/14/2002	0:32:00	32.996	31.989	31.989	9.399	9.165	9.327	27.933	95038	284.674	283.301	284.363
2/14/2002	0:33:00	32.996	31.989	31.989	9.424	9.182	9.33	27.977	95160	285.352	283.594	284.491
2/14/2002	0:34:00	32.996	31.989	32.996	9.448	9.168	9.33	27.988	95242	285.553	283.978	284.766
2/14/2002	0:35:00	32.996	31.989	32.996	9.467	9.201	9.341	28.048	95406	285.388	283.667	284.509
2/14/2002	0:36:00	32.996	31.989	31.989	9.418	9.176	9.319	27.938	95160	285.315	284.07	284.454
2/14/2002	0:37:00	32.996	31.989	31.989	9.391	9.207	9.311	27.982	94814	285.663	284.747	284.93
2/14/2002	0:38:00	32.996	31.989	32.996	9.443	9.207	9.366	28.01	95140	285.352	284.235	284.637
2/14/2002	0:39:00	32.996	31.989	31.989	9.476	9.201	9.344	28.021	95018	285.992	284.583	284.949
2/14/2002	0:40:00	32.996	31.989	31.989	9.435	9.165	9.325	27.933	95406	285.242	283.392	284.216
2/14/2002	0:41:00	32.996	31.989	31.989	9.429	9.179	9.347	27.949	95344	285.205	283.887	284.509

Figure 23 shows the waveform for the turbine side of the transformer during a thunderstorm that occurred on July 17, 2002. During this time, there were lightning strikes on the distribution network and subsequent multiple automatic and manual switching operations. This situation resulted in numerous voltage spikes and sags on the local distribution network.

Table 10 shows a portion of the corresponding turbine data. As can be seen, the switching operations resulting from the thunderstorm caused transients on the distribution network that caused the turbine to trip and reduced service reliability. Although these trips are relatively infrequent, they indicate that surge and lightning suppression should be major concerns in the design of an IES.

Figure 23 shows that this particular disturbance initially occurred on phase B and subsequently propagated to other phases, which caused the turbine to trip as indicated by the phase currents from the generator dropping to zero. As the turbine shut down, there was also a drastic increase in the harmonic content on the turbine side of the transformer. From results reported in Year 1 of this project, it seems likely that this is due to the behavior of the inverter as the transient in reactive power propagates back upon it. It should also be noted that industrial-quality lightning and noise suppression were installed on both sides of the transformer to limit the magnitude of the transient. During the trip, there was also a period of phase imbalance that was of such short duration it should not be a major concern. This imbalance was essentially isolated to the turbine side of the transformer.

This particular installation isolates itself from the grid in the case of loss of grid power. Additional testing needs to be done to determine the influence of harmonics and phase imbalance, in the case of isolation and simultaneous turbine trip, on the loads connected to the isolated bus. Initial indications are that the surge and noise suppression devices connected to the turbine bus would keep these at acceptable levels and prevent equipment damage. In addition, if necessary, tuning of the timing of the transfer operation should greatly reduce the probability of simultaneous events.



Event: 1 Of 79

Duration: 12 Cycles

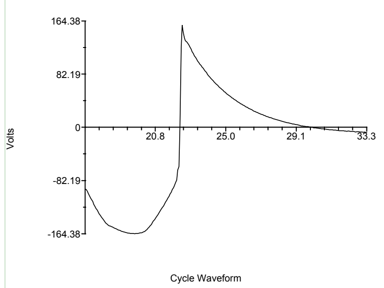
Event Trigger Input 5 Vc Volts (THD)

Event Trigger Cycle 2

Time: 07/17/2002 11:54:22.650

Input: Va Volts

Cycle: 2



Total Harmonic Distortion	85.02 %
Odd Contribution	36.80 %
Even Contribution	76.64 %
RMS Of Fundamental	66.40 V
RMS Of Fund + Harm	91.02 V

Harm	% Of Fund	Volts	Angle	Harm	% Of Fund	Volts	Angle
Fund	100.00	66.4	0°	2	70.20	46.6	41°
3	21.19	14.1	63°	4	21.44	14.2	15°
5	21.38	14.2	50°	6	7.66	5.1	56°
7	12.47	8.3	22°	8	12.11	8.0	58°
9	5.52	3.7	52°	10	9.37	6.2	39°
11	8.35	5.5	73°	12	4.08	2.7	58°
13	7.32	4.9	54°	14	6.07	4.0	89°
15	3.07	2.0	62°	16	6.07	4.0	66°
17	4.79	3.2	102°	18	2.63	1.7	71°
19	5.05	3.4	81°	20	3.82	2.5	117°
21	2.27	1.5	82°	22	4.31	2.9	97°
23	3.07	2.0	131°	24	2.12	1.4	92°
25	3.87	2.6	111°	26	2.58	1.7	145°
27	1.98	1.3	101°	28	3.47	2.3	126°
29	2.20	1.5	159°	30	1.81	1.2	112°
31	3.07	2.0	139°	32	1.85	1.2	170°
33	1.74	1.2	123°	34	2.79	1.9	154°
35	1.53	1.0	183°	36	1.70	1.1	134°
37	2.53	1.7	167°	38	1.26	0.8	192°
39	1.64	1.1	144°	40	2.29	1.5	181°
41	1.03	0.7	202°	42	1.58	1.0	155°
43	2.01	1.3	194°	44	0.83	0.5	211°
45	1.52	1.0	167°	46	1.81	1.2	209°
47	0.68	0.5	215°	48	1.50	1.0	179°
49	1.59	1.1	223°	50	0.55	0.4	217°
51	1.45	1.0	193°	52	1.45	1.0	238°
53	0.48	0.3	220°	54	1.40	0.9	206°
55	1.28	0.9	253°	56	0.43	0.3	222°
57	1.35	0.9	219°	58	1.16	0.8	267°
59	0.37	0.2	220°	60	1.29	0.9	232°
61	1.04	0.7	282°	62	0.35	0.2	222°
63	1.26	0.8	246°				

Figure 23. Waveform during thunderstorm on July 17, 2002

Table 10. Partial Turbine Data for July 17, 2002

Date	Time	Phase A Current A	Phase B Current A	Phase C Current A	Output Power kW	Turbine Speed rpm	Number of Starts
7/24/2002	22:26:00	30.981	30.981	30.981	26.664	96028	103
7/24/2002	22:27:00	30.981	30.981	30.981	26.724	96174	103
7/24/2002	22:28:00	30.981	30.981	30.981	26.719	96070	103
7/24/2002	22:29:00	30.981	30.981	30.981	26.873	95840	103
7/24/2002	22:30:00	30.981	30.981	30.981	26.851	95778	103
7/24/2002	22:31:00	0	0	0	0	85506	103
7/24/2002	22:32:00	0	0	0	0	11170	103
7/24/2002	22:33:00	0	0	0	0	0	103
7/24/2002	22:34:00	1.996	0.989	1.996	1.527	60024	103
7/24/2002	22:35:00	31.989	31.989	31.989	27.702	95592	104
7/24/2002	22:36:00	32.996	31.989	31.989	27.828	95986	104

4.1.1.2 System Reliability

The system performed reliably. No problems were encountered with the CHP system, and the fluid system operated reliably and without leaks. The main heat transfer for the excess heat from the turbine is accomplished with a circulating loop of propylene glycol. This was chosen as the heat transfer medium because it inherently inhibits corrosion and biological growth at the 30% concentration level. It also provides freeze protection in the case of outage.

On several occasions, the memory buffer on the power quality monitors filled, which caused gaps in data acquisition. This is now avoided by downloading the data more frequently.

The system is monitored through the Internet by way of the control system. The Internet interface allows for remote access and has proved reliable for monitoring purposes, but it is often too slow and unreliable for real-time control. For this reason, the local control system is capable of operating the entire system without an Internet connection.

The drive motor on the desiccant wheel failed twice because of an apparent misalignment that occurred at the factory. This issue was resolved with several field modifications of the wheel assembly drive mechanism and alignment.

On several occasions, equipment failure was experienced with the microturbine. Problems also occurred with the inverter, battery, battery control board, fuel compressor, fuel compressor control board, and engine. Recently, the frequency of these problems has decreased.

Table 11 shows outage times for the first half of 2002. The large outage gaps were due to parts replacement on the microturbine. Smaller-duration outages were due to turbine trips caused by grid transients or routine maintenance activities.

Table 11. Outage Experience for First Half of 2002

2002 Date	Time of Outage
Jan. 18	4:56–5:00
Jan. 23	1:05–1:10
Feb. 10	18:19–23:59
Feb. 11	00:00–13:54
Feb. 13–15	13:59–13:39
Feb. 18	11:05–11:19
Feb. 22	16:12–16:17
Feb. 26–March 15	6:17–11:45
April 16–17	6:15–4:45
May 13	10:44–11:01
May 17	9:20–10:53
May 30–31	14:47–16:13
May 31	9:43–11:10

4.1.2 Small Office Building Site

A small office building was chosen for this part of Task 6 because it was possible to more accurately characterize the building and its occupancy patterns. Various CHP systems were installed in the building, and data were gathered about the relative merit of the systems, the interaction of the systems with one another, and the conventional HVAC system. The conventional HVAC system consisted of electric baseboard heat and conventional air conditioning.

Figures 24 through 27 show the test configuration for the four cases considered in this phase of the work.

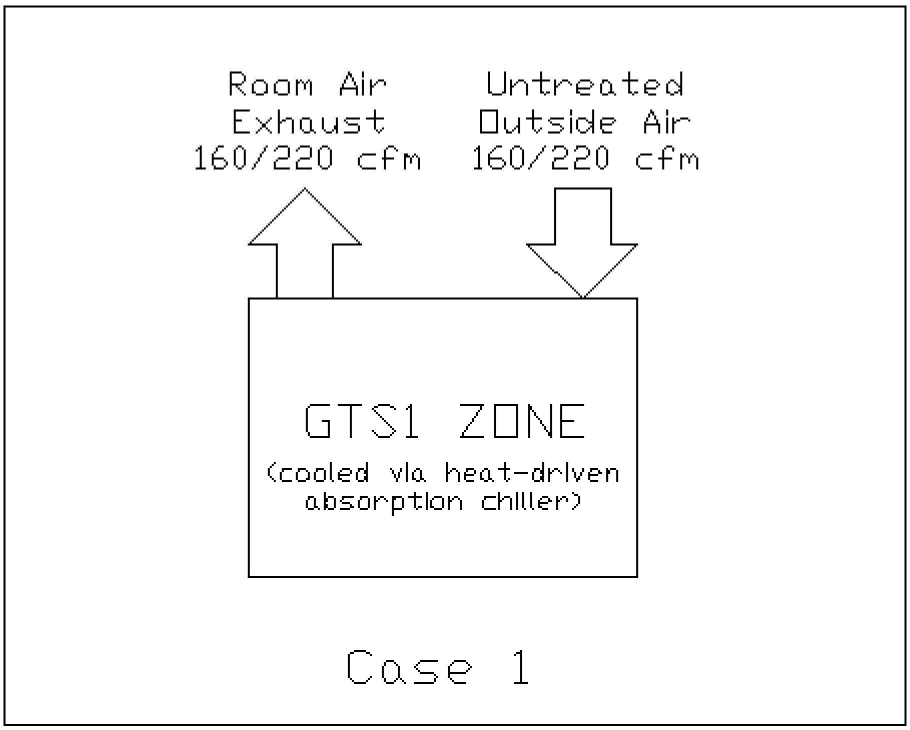


Figure 24. Case 1 physical design

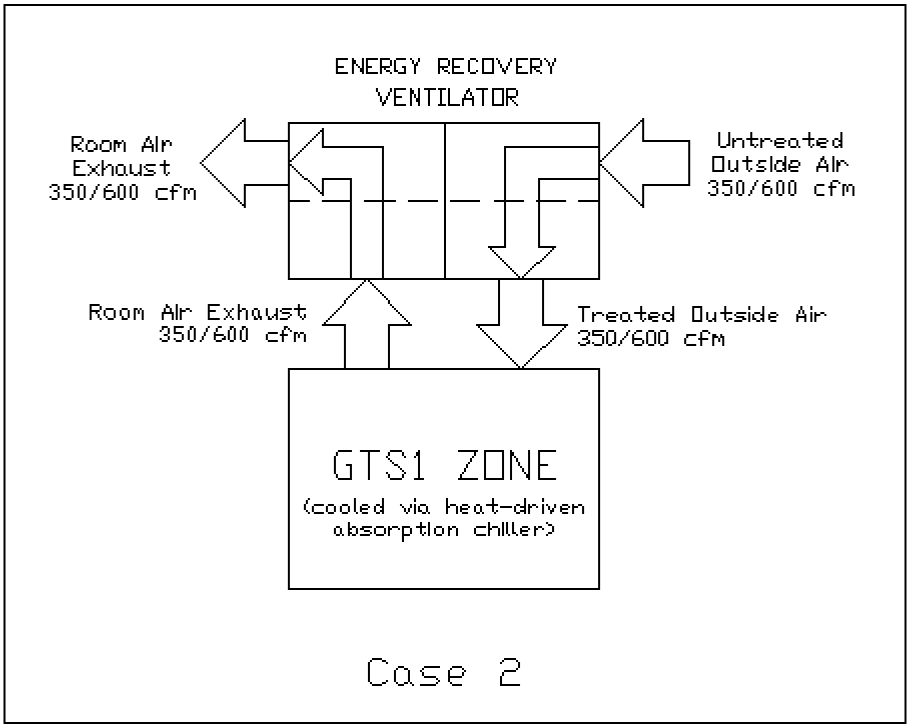


Figure 25. Case 2 physical design

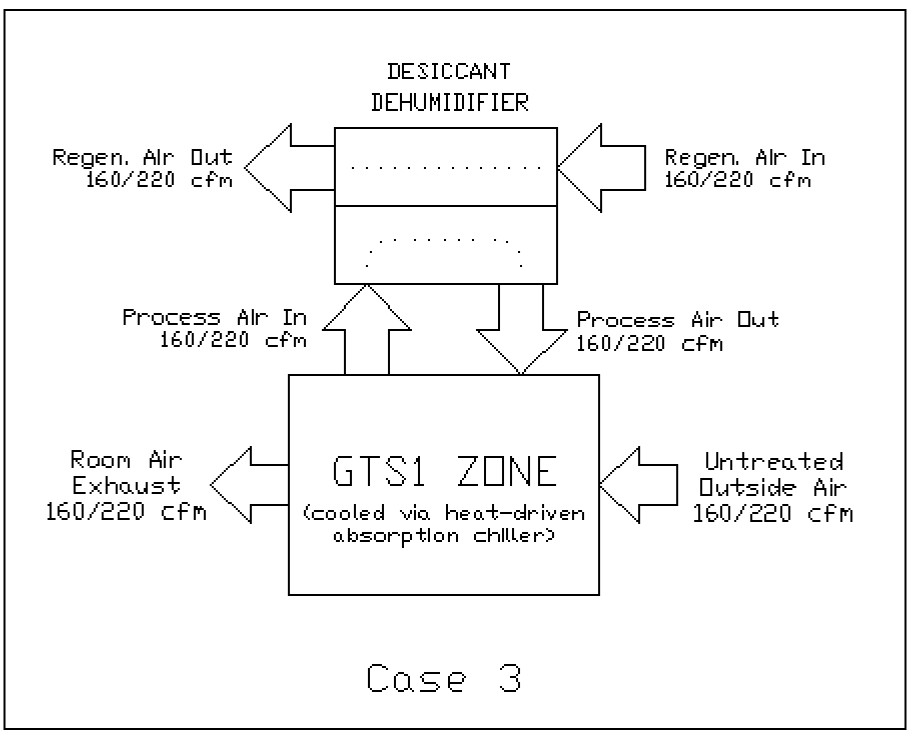


Figure 26. Case 3 physical design

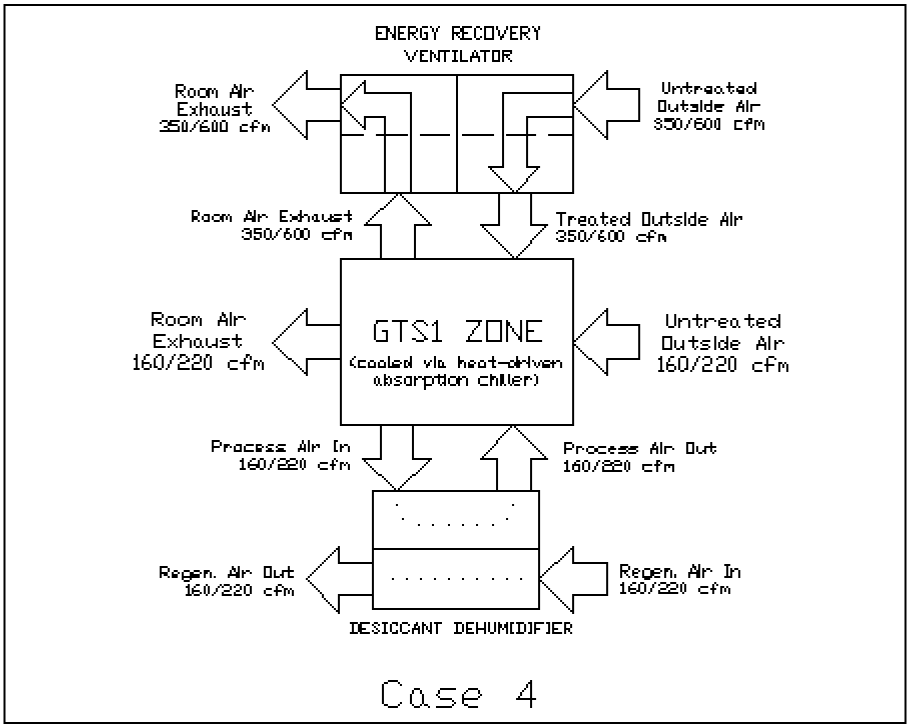


Figure 27. Case 4 physical design

Data were gathered by two data acquisition systems. The first was a computer with LabTech Control, and the second was an Enflex Controller. These systems allowed for a complete characterization of the tests in real time.

Two packaged CHP systems, shown in Figure 28, provided electricity for the building and heat for building heating or cooling through an absorption cooler. All office building tests were performed in grid-connected mode. Each of these packaged systems consisted of a 30-kW microturbine with heat recovery, control, and pumping systems.

The CHP systems installed in the building consisted of:

- A control and data acquisition system, shown in Figure 29
- A desiccant dehumidifier, shown in Figure 30
- A heat exchanger for absorber-based cooling, shown in Figure 31
- A heater for building heating, shown in Figure 32
- An energy recovery vent (ERV), shown in Figure 33.

Figure 28. Two packaged CHP systems
(Boxes on either side of the absorption chiller skid)

Figure 29. Control panel

Figure 30. Desiccant dehumidification unit

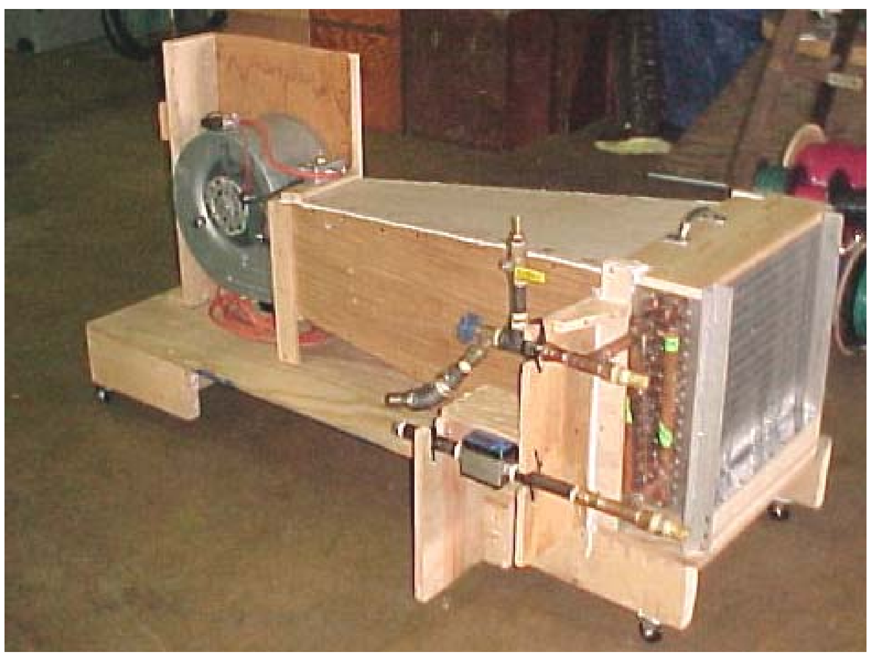


Figure 31. Cooling heat exchanger

Figure 32. Heat exchanger

Figure 33. Energy recovery vent

4.1.2.1 CHP Component Tests and Interactions

Various cases were run for different combinations of CHP components.[3] These tests were statistically based to determine any interactions among the CHP devices. One objective was to determine if one or more CHP devices could show an advantage over conventional HVAC systems.

The test cases were organized as follows:

- Case 1: Outside air introduced through power vent only (the power vent consisted of a fan and duct work to bring outside air into the building with no conditioning)
- Case 2: Outside air introduced to the building through the ERV only
- Case 3: Outside air introduced to the building through the power vent and the CHP desiccant dehumidification unit (the desiccant unit recirculated air within the building for the dehumidification path, and outside air was heated for regeneration and then exhausted to the outside without entry into the building).
- Case 4: Outside air introduced through the power vent plus outside air through the ERV plus desiccant dehumidification.

The results from each of the cases are discussed in the following sections. For all the cases, a randomized test matrix was assembled for combinations of high and low values of the parameters of interest. The low value of the factor is coded as –1 and the high value as +1 for ease of recording. Each test sequence is run in the order shown in the table to ensure randomization.

4.1.2.1.1 Case 1

In Case 1, outside air was introduced through a conventional power vent. This was basically a reference case to consider how the building reacted to varying amounts of outside air exchange.

Table 12 shows the experimental design for Case 1. For Case 1, the only effect that showed significance was for conventional air conditioner power with inside temperature. This result was expected and verified the use of this case as a reference.

[3] The Design-Ease computer program from Stat-Ease Inc. was used to speed the calculations.

Table 12. Case 1 Experimental Design

Case	Trial	Run	Factor 1 A: Air Flow Hi-Lo	Factor 2 B: Inside Temp Hi-Lo	Response 1 Delta In-Out Humidity lb H_2O/lb Air (Final)	Response 2 H_2O into Bldg lb (Total)	Response 3 Inside Humidity lb H_2O/lb Air (Final)	Response 4 A/C Power Actual Btu/hr (Average)	Response 5 Delta In-Out Temp °F (Final)
1	1	1	1.00	-1.00	0.0048	11.98	0.0157	6762	7.4
1	1	2	-1.00	-1.00	-0.0027	10.01	0.0082	7354	-4.8
1	1	3	-1.00	1.00	-0.0036	8.93	0.0077	1073	-6.1
1	1	4	1.00	1.00	-0.0009	12.32	0.0112	46	-3.1
1	2	1	1.00	-1.00	-0.0040	6.85	0.0085	8199	-4.9
1	2	2	-1.00	-1.00	-0.0011	6.51	0.0113	8529	-3.4
1	2	3	-1.00	1.00	-0.0031	4.67	0.0100	1659	-3.2
1	2	4	1.00	1.00	-0.0029	5.68	0.0102	118	-2.9
1	3	1	1.00	-1.00	0.0033	7.32	0.0100	5813	12.3
1	3	2	-1.00	-1.00	0.0029	6.76	0.0095	7002	10.4
1	3	3	-1.00	1.00	0.0027	3.62	0.0094	1412	10.4
1	3	4	1.00	1.00	0.0022	5.97	0.0096	144	10.7
1	4	1	1.00	-1.00	0.0015	0.82	0.0056	5352	6.4
1	4	2	-1.00	-1.00	0.0024	0.49	0.0064	6062	5.6
1	4	3	-1.00	1.00	0.0017	0.47	0.0057	8267	9.5
1	4	4	1.00	1.00	0.0016	0.66	0.0057	8048	9.5
1	5	1	1.00	-1.00	0.0008	0.50	0.0038	5492	20.7
1	5	2	-1.00	-1.00	0.0007	0.37	0.0037	5768	22.3
1	5	3	-1.00	1.00	0.0009	0.38	0.0039	5024	26.5
1	5	4	1.00	1.00	0.0009	0.51	0.0039	6410	25.9

Factorial experimental designs are used when there are several factors and it is desired to study the joint effect of the factors on the response. In this case, it is used to consider how the operating parameters of CHP systems influence effectiveness. An initial screening approach in which k factors each at two levels is used. This is generally referred to as a 2^k design.[4]

It is beneficial to construct a model of the response of the system to aid in understanding and predicting results. One assumption in such a model is that the errors are normally and independently distributed with zero mean and constant variance. A check of the normality assumption can be done by plotting the residuals, the difference between the measured and expected values from calculations. This should resemble a normal distribution centered at zero. Another approach is to do a normal probability plot of the residuals. The residuals are arranged in increasing order. If the underlying error distribution is normal, then the graph should be a straight line. Also, on a plot of residuals versus time, there should be no apparent pattern if the assumptions of independence, constant variance, and normality are satisfied.

For two-level factorial designs, a normal probability plot can be used to choose significant effects, or design factors that significantly affect system performance. A plot of the ordered values of a sample versus the expected ordered values from the true population should be approximately a straight line. If the effects represent a sample from a normal population, they should form approximately a straight line on a normal probability plot of the effects. Usually, the few important effects show up as outliers on the normal probability plot. The Case 1 data for air conditioner power are shown in Figure 34.

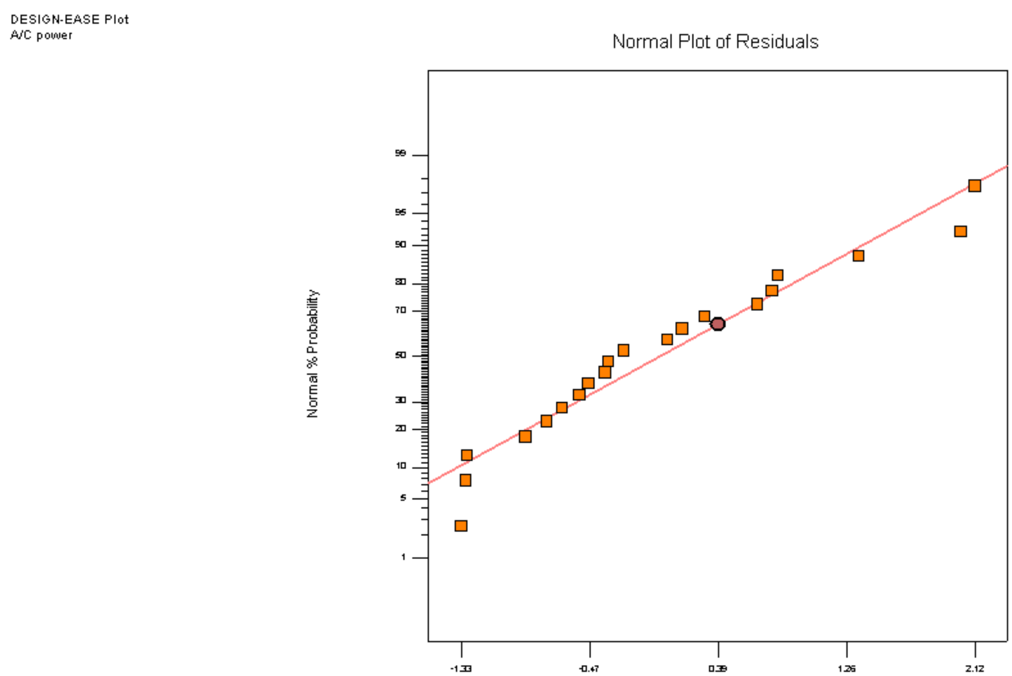


Figure 34. Normal probability plot for Case 1 air conditioner power

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[4] Further details can be found in “Statistics for Experimenters” by Box and Hunter or “Design and Analysis of Experiments” by Montgomery.

A half normal plot can also be used to select significant effects. It is similar to the normal probability plot except that the sign of the effect is ignored when plotted. Effects that show up along the straight line are negligible, and points far from the line indicate large effects. Large absolute values show up as outliers in the upper-right of the graph. In this case, B, inside temperature, is such a point.

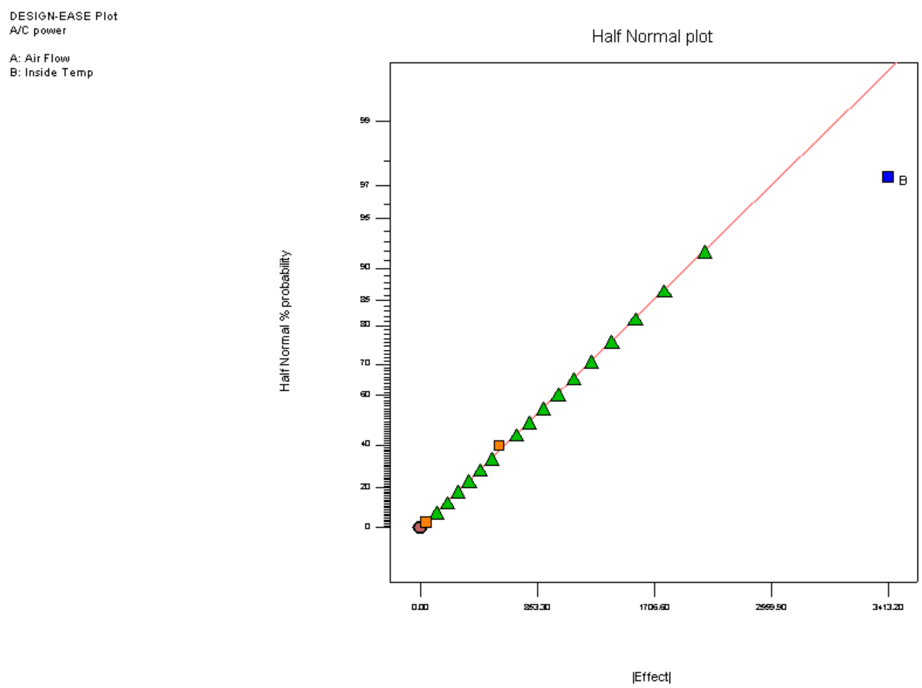

Figure 35. Half normal plot of residuals for air conditioner power

This half normal plot was assembled from the data to aid in choosing the parameters of the following model.

A/C power = +4926.70000 - 1706.60000 * Inside Temp

The analysis for this model follows.

A/C power analysis of variance analysis
Analysis of variance [Partial sum of squares]

Source	Sum of Squares	DF	Mean Square	F Value
Model	5.825E+007	1	5.825E+007	9.27
B	5.825E+007	1	5.825E+007	9.27
Residual	1.131E+008	18	6.283E+006	
Lack of Fit	1.671E+006	2	8.357E+005	0.12
Pure Error	1.114E+008	16	6.964E+006	
Cor Total	1.713E+008	19		

The Model F value of 9.27 implies the model is significant. There is only a 0.70% chance that a Model F value this large could occur because of noise.

Results for Case 1 for air conditioner power can be seen in Figure 36. None of the other responses indicated statistically significant models. For this simple case, the expected result is that the major influence on the air conditioner power is the inside temperature of the building. Case 1 verifies that the data acquisition and analysis systems were operating correctly and producing the correct conclusions for a simple case.

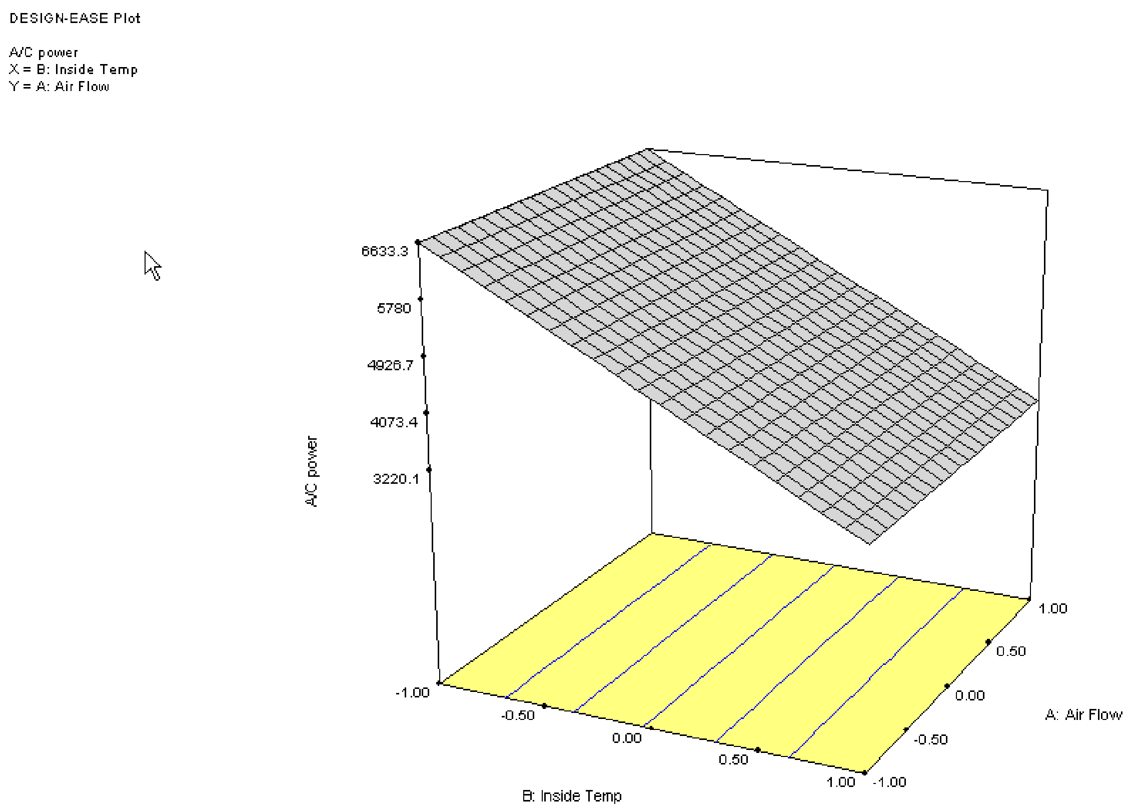

Figure 36. Results from Case 1 for air conditioner power

Additional analysis results can be found in Appendix C for Case 1.

4.1.2.1.2 Case 2

For Case 2, outside air was introduced to the building only through the ERV. The ERV introduces fresh air to a building without the addition or removal of heat while maintaining the humidity of the inside air level. It consists of a sensible plastic wheel coated with silica gel. No outside energy is used to regenerate the wheel. The only energy used by the vent is electricity for two small blowers and a motor to turn the wheel. This case was run to establish baseline data for the response of the ERV and potential interactions with the building systems. The influence of this device on the operation of the CHP system is important because it uses little energy and has the potential to displace CHP or conventional technology under certain weather conditions.

Figures 37 through 40 show that the ERV effectiveness is influenced by the fan speed of the ERV unit. This is to be expected because the fans govern how much outside air is introduced into the building. Eventually, the system should reach its maximum capacity, but because the installed fans were undersized, there was a linear change in the water transferred by the system.

The unit also performed the heat transfer function as quoted in the manufacturer specifications. The ERV is designed to introduce outside air into a building with temperature and humidity near inside conditions. The temperature difference response of the unit to Fan 1 speed and inside temperature is as expected. From the figures, it can be observed that this device is thus an alternative to CHP-driven chilling and dehumidification in cases in which there are low levels of temperature and humidity variation.

The cost of this unit is low, and its operating cost is very low because it contains only two small fans and a drive motor. In cases in which the primary concern is to introduce fresh air into a building with no major heat or humidity sources, the cost of installing heat recovery equipment and piping and operating a CHP-driven alternative may not be justified. The ERV maintains the air introduced from outside to near inside air conditions. At extremes of temperature and humidity, its performance decreases slightly.

Table 13 shows the experimental design for Case 2. Additional results can be found in Appendix D.

Table 13. Case 2 Experimental Design

Case	Trial	Run	Factor 1 A: Fan 1 Speed Hi-Lo	Factor 2 B: Fan 2 Speed Hi-Lo	Factor 3 C: Inside Temp Hi-Lo	Response 1 Delta In-Out Humidity lb H_2O/lb Air (Final)	Response 2 H_2O into Bldg lb (Total)	Response 3 Inside Humidity lb H_2O/lb Air (final)	Response 4 A/C Power Actual Btu/hr (Average)	Response 5 Delta In-Out Temp °F (Final)
2	1	1	1.00	-1.00	1.00	-0.0003	21.6	0.0143	792	4.4
2	1	2	-1.00	1.00	1.00	-0.0014	38.1	0.0125	4632	7.1
2	1	3	1.00	-1.00	-1.00	0.0025	22.8	0.0144	8801	10.7
2	1	4	-1.00	-1.00	-1.00	0.0038	21.4	0.0142	9150	11.1
2	1	5	-1.00	-1.00	1.00	0.0018	16.4	0.0093	-69	3.6
2	1	6	-1.00	1.00	-1.00	0.0038	47.3	0.0117	6412	9.9
2	1	7	1.00	1.00	1.00	0.0037	30.1	0.0115	654	11.4
2	1	8	1.00	1.00	-1.00	0.0033	36.3	0.0109	8347	12.8
2	2	1	1.00	-1.00	1.00	0.0014	8.2	0.0044	5478	29.1
2	2	2	-1.00	1.00	1.00	0.0012	10.5	0.0042	6166	28.9
2	2	3	1.00	-1.00	-1.00	0.0010	7.1	0.0039	8264	24.5
2	2	4	-1.00	-1.00	-1.00	0.0011	7.4	0.0039	7088	24.0
2	2	5	-1.00	-1.00	1.00	0.0011	8.2	0.0043	6498	27.9
2	2	6	-1.00	1.00	-1.00	0.0009	9.9	0.0040	6431	22.6
2	2	7	1.00	1.00	1.00	0.0010	10.5	0.0040	6898	26.0
2	2	8	1.00	1.00	-1.00	0.0010	10.0	0.0039	7044	20.8

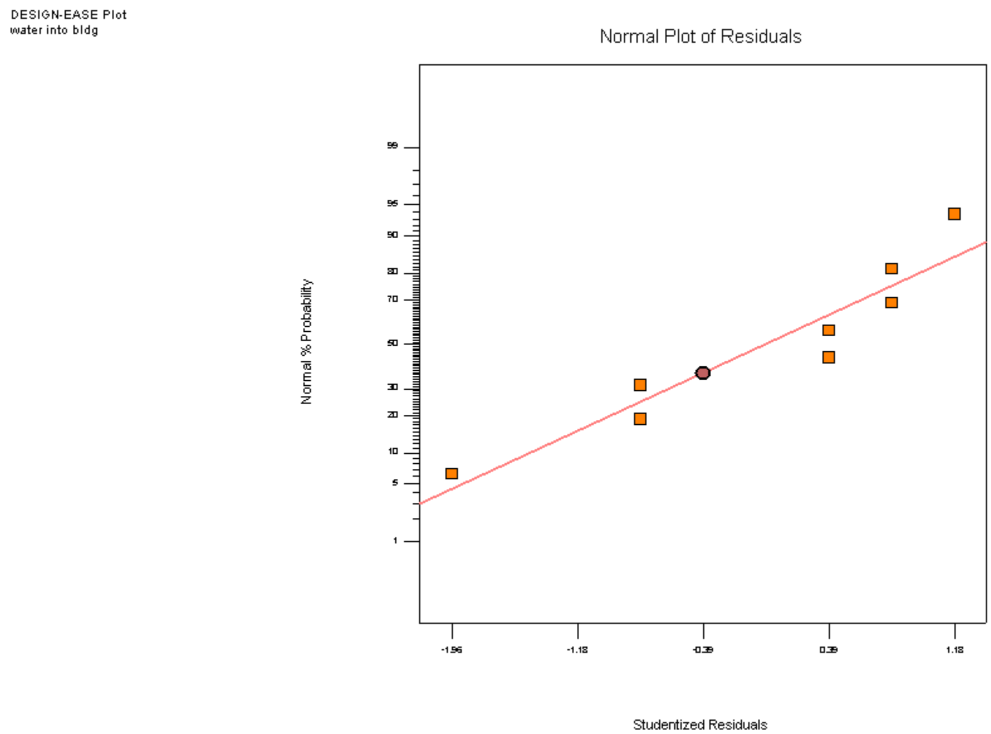

Figure 37. Normal plot of residuals for Response 2

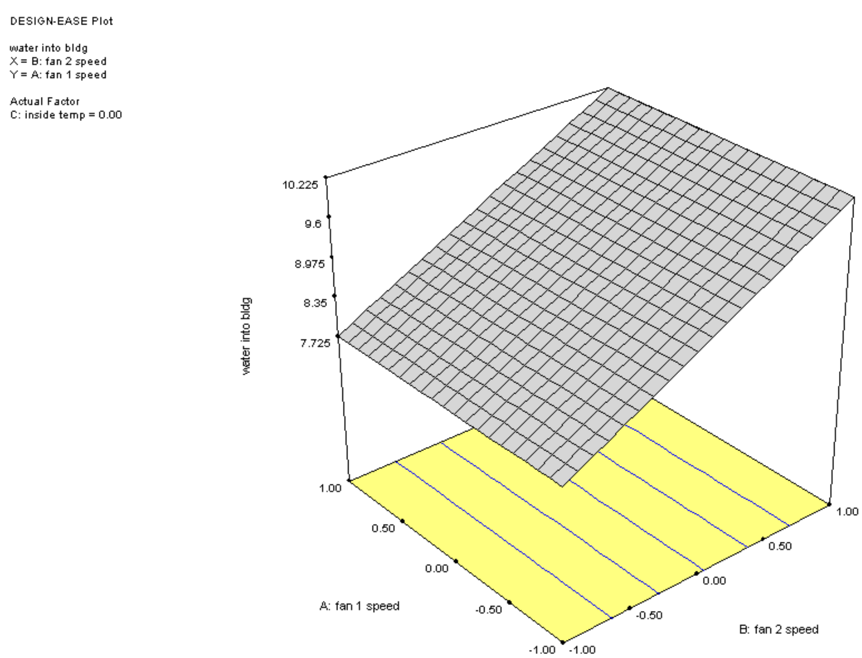

Figure 38. Results for Response 2

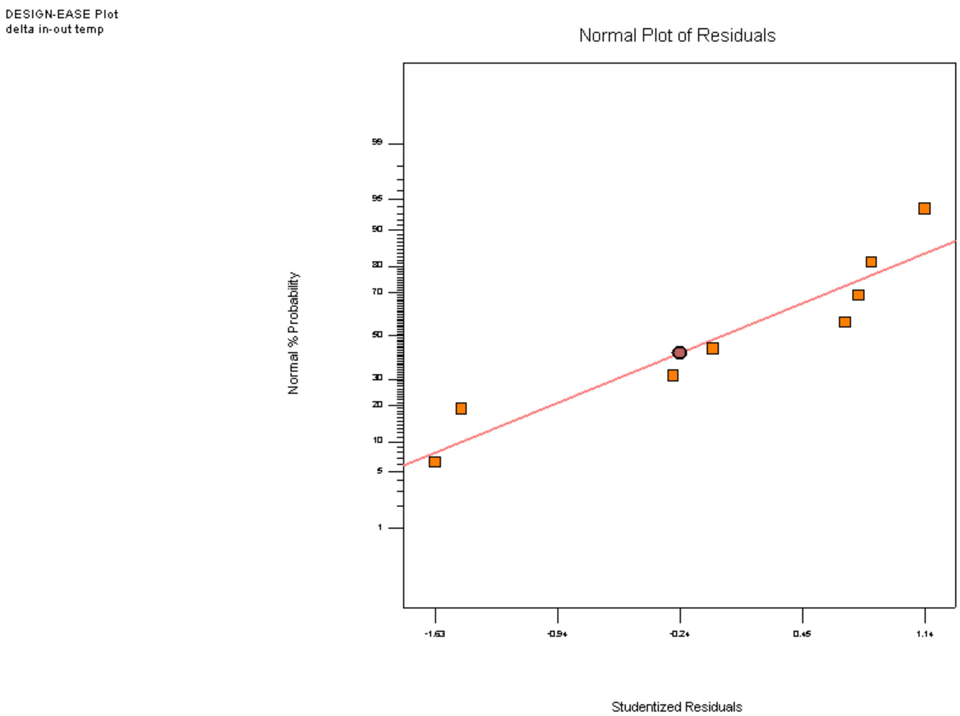

Figure 39. Normal plot of residuals for Response 5

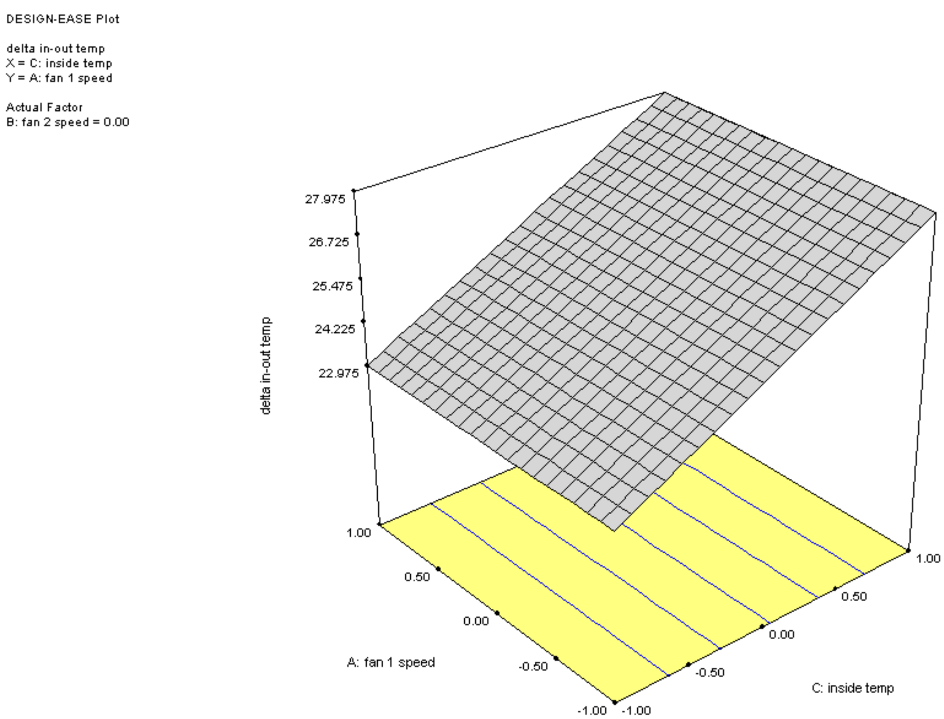

Figure 40. Results for Response 5

4.1.2.1.3 Case 3

For Case 3, outside air was introduced by the power vent, and the inside air was dehumidified with a CHP-driven desiccant dehumidification unit that recirculated building air. Desiccant dehumidification is of interest for CHP systems because the design uses waste heat. As humidity is reduced, room temperature can be increased—thereby reducing electric air conditioning costs. This case examines the efficiency sensitivity of the desiccant dehumidification and how it interacts with the conventional HVAC system.

Table 14 shows the experimental design for Case 3. Additional information can be found in appendices A and E.

Table 14. Case 3 Experimental Design

Case	Trial	Std	Run	Block	Factor 1 A: Inside Temp F	Factor 2 B: Desiccant Regen Temp F	Factor 3 C: Outside Air Flow CFM	Response 1 Delta In-Out Humidity lb H_2O/lb Air (Final)	Response 2 H_2O Into Bldg lb (Total)	Response 3 Inside Humidity lb H_2O/lb Air (Final)	Response 4 A/C Power Actual Btu/hr (Average)	Response 5 Delta In-Out Temp °F (Final)
3	1	6	1	Block	1.00	1.00	-1.00	0.0013	0.36	0.0042	8729	25.4
3	1	7	2	Block	1.00	-1.00	1.00	0.0013	0.48	0.0042	7039	25.1
3	1	2	3	Block	1.00	-1.00	-1.00	0.0011	0.36	0.0040	7548	26.2
3	1	1	4	Block	-1.00	1.00	-1.00	0.0008	0.36	0.0037	7124	23.7
3	1	5	5	Block	-1.00	-1.00	1.00	0.0008	0.50	0.0037	6263	21.7
3	1	3	6	Block	-1.00	-1.00	-1.00	0.0005	0.40	0.0036	6617	23.0
3	1	8	7	Block	1.00	1.00	1.00	0.0009	0.50	0.0037	8254	26.2
3	1	4	8	Block	-1.00	1.00	1.00	0.0004	0.52	0.0035	6406	23.0

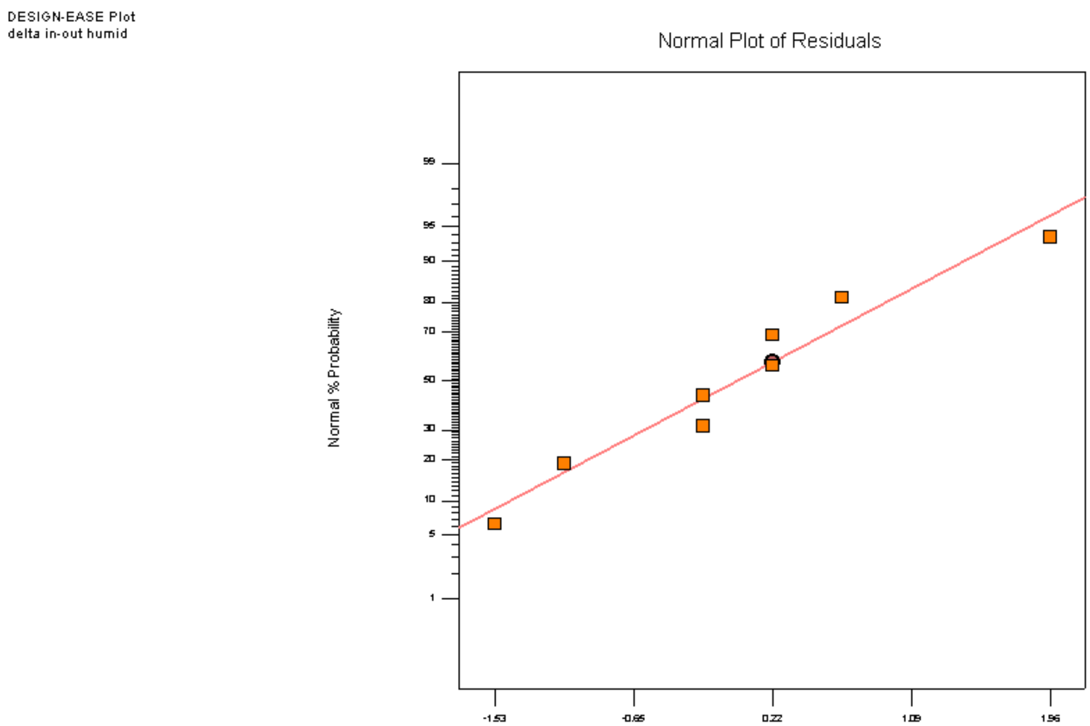

Figure 41. Normal plot of residuals for Response 1 (delta in-out humidity)

The behavior of the system shows particular sensitivity of Response 1 (the difference between inside and outside humidity) to changes in outside air flow. This is demonstrated by the change in the shape of the responses of figures 42 through 44 as the outside air flow is changed across its range of possible values. As outside air flow increases, there is a significant increase in delta in-out humidity for lower desiccant regeneration and inside temperatures. Also, there is a less significant decrease in delta in-out humidity as desiccant regeneration and inside temperature increase for this case. In contrast, for low levels of outside air flow, delta in-out humidity increases for high desiccant regeneration temperatures combined with low values of inside temperature. Also, there is a small decrease in delta in-out humidity for high values of inside temperature combined with low desiccant regeneration temperatures.

This type of information is important in the design of a control system and when choosing CHP devices to provide the maximum benefit for a particular application. In this case, it is desirable to keep regeneration temperature low while decreasing humidity as much as possible. To do this, it would be advisable to design the system for low values of outside air flow. This would tend to decrease the required regeneration temperature.

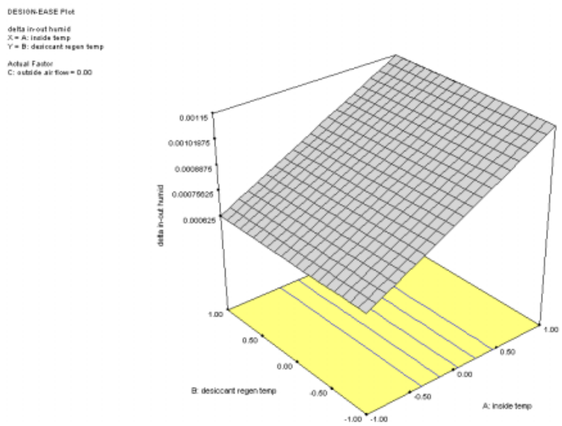

Figure 42. Results for Response 1 with outside air flow at 0 level

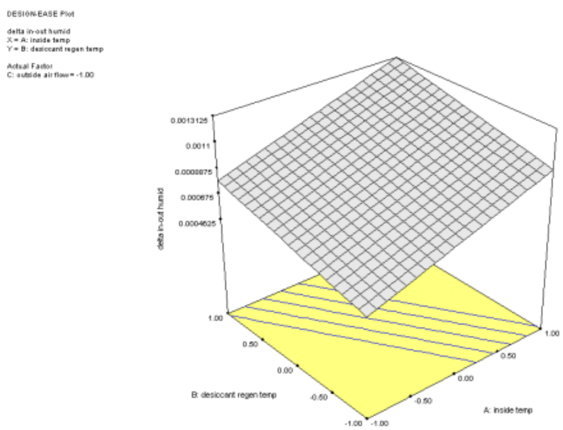

Figure 43. Results for Response 1 with outside air flow set to –1 level

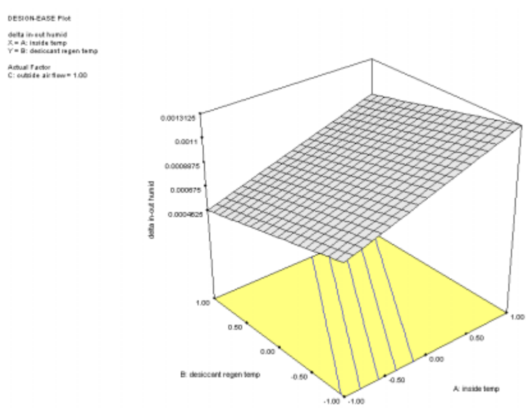

Figure 44. Results for Response 1 with outside air flow set to +1 level

Response 2 is the amount of water introduced into the building. It was chosen as a factor because a major concern for comfort is the humidity level. This response indicated how much water would have to be removed to maintain a set comfort level based on humidity. The only factor that showed any influence was the outside air flow. This is to be expected because the outside air contribution to humidity is far greater than that made by the people at the occupancy level used for the test. This test allowed for an evaluation of the effectiveness of the CHP regenerated desiccant system.

Response 5 is the difference of inside and outside temperatures. The only factor that showed significant influence on the response was the inside temperature. This indicates that the heat attributable to the operation of the desiccant system was so small compared with the heat from the outside propagating into the building and the heat from the occupants that it is indistinguishable from noise in the modeled system.

The other factors showed no significant effect on this response. Such data are useful in determining what factors are most important in the design and control of a CHP system. By using this information, it is possible to assign priorities to those factors that have the most influence on CHP system performance. By looking at the slope of the graphs, it is also possible to gain information about the response potential for a particular control variable that then can be used to initially set up proportional integral derivative control parameters.

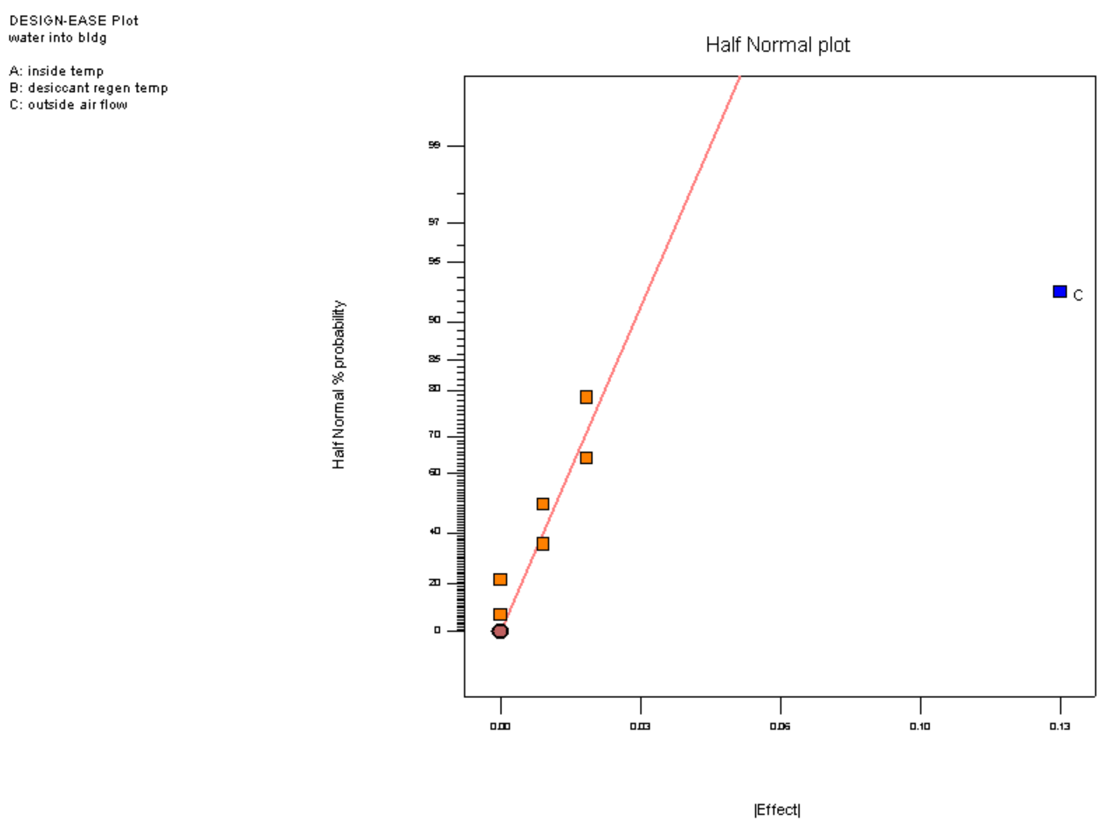

Figure 45. Half normal plot for Response 2 (water introduced into building)

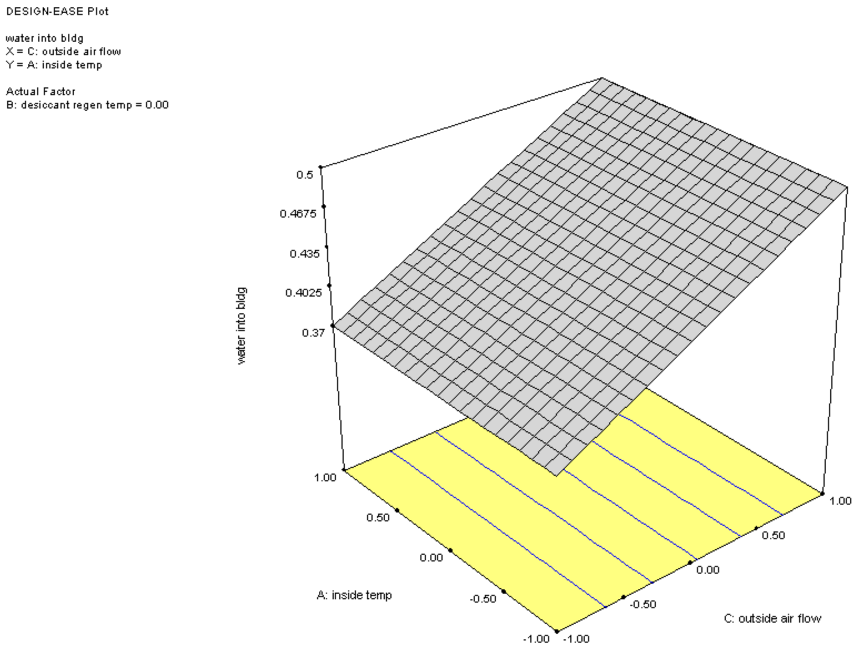

Figure 46. Results for Response 2 (water introduced into building)

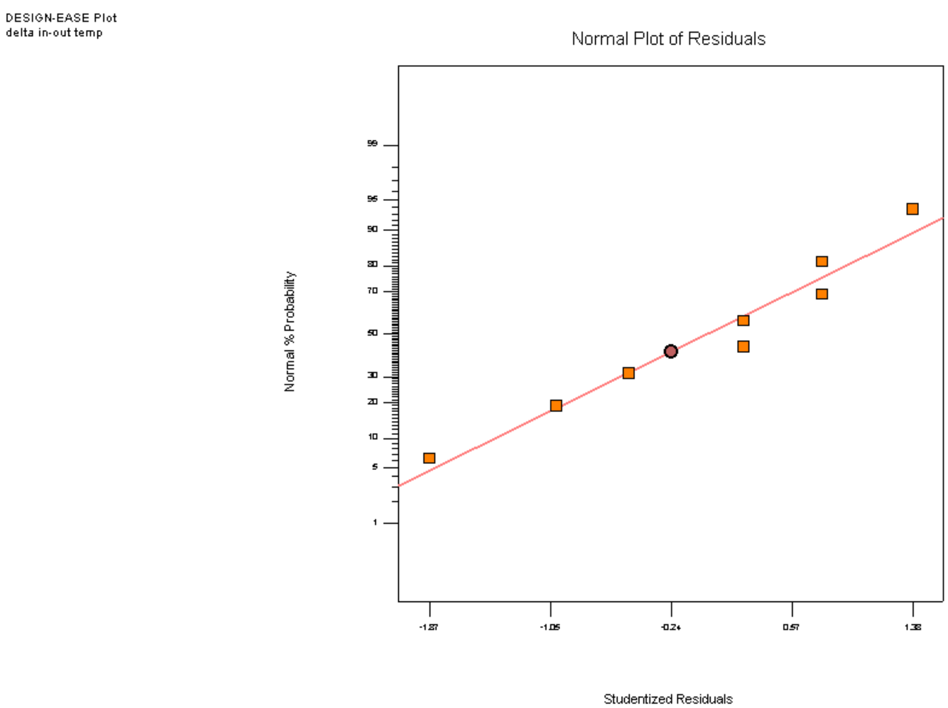

Figure 47. Normal plot of residuals for Response 4 (delta in-out temperature)

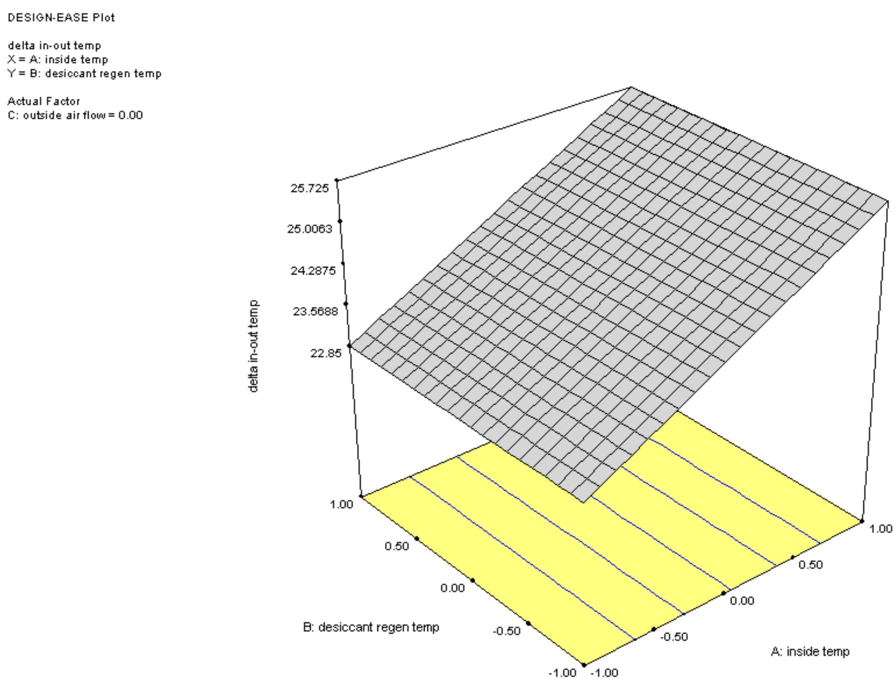

Figure 48. Results for Response 4 (delta in-out temperature)

4.1.2.1.4 Case 4

Case 4 has:

- Outside air entering the building through the power vent
- Outside air entering the building through the ERV
- CHP-driven desiccant dehumidification
- Conventional as well as CHP-driven absorption air conditioning.

This case is intended to identify the interactions that may be present when all three systems operate simultaneously. The addition of air through the power vent and the ERV is used to estimate the influence of noncontrollable air infiltration into the building. It also considers the case in which the ERV does not have the capacity to supply all the air required by building codes and hence needs to be supplemented by direct outside sources.

Because of the number of factors involved, a half factorial design was chosen. This reduces the number of tests and provides good results for this case because there are no significant three-factor interactions present. In this case, the response of individual systems was of a magnitude and nature consistent with a half factorial design. Using this approach, it was possible to use 64 rather than 128 tests with no loss of information.

Table 15 shows the experimental design for Case 4. Additional information can be found in appendices B and F.

Table 15. Case 4 Experimental Design

Case	Std	Run	Factor 1 A: Inside Starting Temp Hi-Lo	Factor 2 B: Inside Starting Humidity Hi-Lo	Factor 3 C: Outside Airflow into Bldg Hi-Lo	Factor 4 D: ERV Supply Fan Speed Hi-Lo	Factor 5 E: ERV Exhaust Fan Speed Hi-Lo	Factor 6 F: Desiccant Regen Airflow Hi-Lo	Factor 7 G: Desiccant Regen Temp Hi-Lo	Response 1 Humidity Time Constant (Sec)	Response 2 Delta In-Out Humidity lb H_2O/lb Air (Start)	Response 3 A/C Power Actual Btu/hr (Average)	Response 4 Inside Humidity lb H_2O/lb Air (Final)	Response 5 Delta In-Out Temp °F (Final)	Response 6 Delta In-Out Humidity lb H_2O/lb Air (Final)	Response 7 Inside Temp °F (Final)
4	57	1	-1.00	-1.00	-1.00	1.00	1.00	1.00	-1.00	255	0.0043	9845	0.0064	0.2	0.0022	72.7
4	32	2	1.00	1.00	1.00	1.00	1.00	-1.00	-1.00	240	0.0054	8392	0.0072	2.8	0.0031	75.7
4	58	3	1.00	-1.00	-1.00	1.00	1.00	1.00	1.00	255	0.0053	9730	0.0069	3.6	0.0028	76.2
4	13	4	-1.00	-1.00	1.00	1.00	-1.00	-1.00	1.00	675	0.0037	8859	0.0069	0.5	0.0028	72.4
4	50	5	1.00	-1.00	-1.00	-1.00	1.00	1.00	-1.00	210	0.0043	8025	0.0072	3.7	0.0032	75.2
4	29	6	-1.00	-1.00	1.00	1.00	1.00	-1.00	-1.00	405	0.0037	8707	0.0071	-0.1	0.0030	71.7
4	22	7	1.00	-1.00	1.00	-1.00	1.00	-1.00	-1.00	300	0.0018	7829	0.0082	7.4	0.0006	75.1
4	61	8	-1.00	-1.00	1.00	1.00	1.00	1.00	1.00	300	0.0034	7049	0.0060	2.2	0.0018	72.2
4	33	9	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	585	0.0042	9351	0.0067	0.8	0.0023	71.7
4	24	10	1.00	1.00	1.00	-1.00	1.00	-1.00	1.00	330	0.0040	11461	0.0066	2.1	0.0022	75.4
4	21	11	-1.00	-1.00	1.00	-1.00	1.00	-1.00	1.00	390	0.0028	10456	0.0068	0.2	0.0023	73.5
4	19	12	-1.00	1.00	-1.00	-1.00	1.00	-1.00	1.00	375	0.0043	10854	0.0077	2.6	0.0011	73.5
4	64	13	1.00	1.00	1.00	1.00	1.00	1.00	1.00	210	0.0048	9184	0.0088	6.6	0.0013	76.6
4	6	14	1.00	-1.00	1.00	-1.00	-1.00	-1.00	1.00	195	0.0013	11120	0.0079	2.8	0.0006	72.2
4	63	15	-1.00	1.00	1.00	1.00	1.00	1.00	-1.00	780	0.0008	10076	0.0090	5.9	0.0012	74.2
4	60	16	1.00	1.00	-1.00	1.00	1.00	1.00	-1.00	405	0.0017	9605	0.0094	8.2	0.0010	75.7
4	56	17	1.00	1.00	1.00	-1.00	1.00	1.00	-1.00	165	0.0009	11766	0.0087	7.7	0.0000	74.4
4	51	18	-1.00	1.00	-1.00	-1.00	1.00	1.00	-1.00	300	-0.0004	10544	0.0088	5.5	0.0003	72.5
4	3	19	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	-1.00	645	0.0003	10148	0.0088	5.9	-0.0001	72.2
4	1	20	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	1.00	480	0.0053	10169	0.0042	11.8	0.0022	71.1
4	10	21	1.00	-1.00	-1.00	1.00	-1.00	-1.00	1.00	285	0.0072	9195	0.0046	14.3	0.0027	73.7
4	37	22	-1.00	-1.00	1.00	-1.00	-1.00	1.00	1.00	210	0.0046	9766	0.0039	10.3	0.0020	69.8
4	26	23	1.00	-1.00	-1.00	1.00	1.00	1.00	-1.00	270	0.0039	8446	0.0067	18.8	0.0014	74.5

Case	Std	Run	Factor 1 A: Inside Starting Temp Hi-Lo	Factor 2 B: Inside Starting Humidity Hi-Lo	Factor 3 C: Outside Airflow into Bldg Hi-Lo	Factor 4 D: ERV Supply Fan Speed Hi-Lo	Factor 5 E: ERV Exhaust Fan Speed Hi-Lo	Factor 6 F: Desiccant Regen Airflow Hi-Lo	Factor 7 G: Desiccant Regen Temp Hi-Lo	Response 1 Humidity Time Constant (Sec)	Response 2 Delta In-Out Humidity lb H_2O/lb Air (Start)	Response 3 A/C Power Actual Btu/hr (Average)	Response 4 Inside Humidity lb H_2O/lb Air (Final)	Response 5 Delta In-Out Temp °F (Final)	Response 6 Delta In-Out Humidity lb H_2O/lb Air (Final)	Response 7 Inside Temp °F (Final)
4	48	24	1.00	1.00	1.00	1.00	-1.00	1.00	-1.00	360	0.0063	7684	0.0069	19.1	0.0018	74.8
4	36	25	1.00	1.00	-1.00	-1.00	-1.00	1.00	-1.00	315	0.0032	8828	0.0059	17.9	0.0006	73.6
4	49	26	-1.00	-1.00	-1.00	-1.00	1.00	1.00	1.00	360	0.0028	8562	0.0059	16.0	0.0010	71.2
4	31	27	-1.00	1.00	1.00	1.00	1.00	-1.00	1.00	255	0.0029	7597	0.0048	19.0	0.0001	68.0
4	38	28	1.00	-1.00	1.00	-1.00	-1.00	1.00	-1.00	180	0.0061	8340	0.0056	19.3	0.0010	73.4
4	46	29	1.00	-1.00	1.00	1.00	-1.00	1.00	1.00	150	0.0048	9189	0.0053	18.7	0.0010	74.3
4	17	30	-1.00	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	165	0.0035	8621	0.0054	15.8	0.0009	70.6
4	44	31	1.00	1.00	-1.00	1.00	-1.00	1.00	1.00	195	0.0045	9630	0.0054	18.2	0.0006	73.4
4	28	32	1.00	1.00	-1.00	1.00	1.00	-1.00	1.00	225	0.0054	9160	0.0057	19.1	0.0006	73.8
4	23	33	-1.00	1.00	1.00	-1.00	1.00	-1.00	-1.00	135	0.0060	5802	0.0046	19.4	0.0017	71.6
4	62	34	1.00	-1.00	1.00	1.00	1.00	1.00	-1.00	135	0.0057	6795	0.0045	21.8	0.0016	74.1
4	14	35	1.00	-1.00	1.00	1.00	-1.00	-1.00	-1.00	150	0.0058	7552	0.0045	21.5	0.0015	74.4
4	41	36	-1.00	-1.00	-1.00	1.00	-1.00	1.00	1.00	150	0.0044	6502	0.0046	19.4	0.0011	71.1
4	39	37	-1.00	1.00	1.00	-1.00	-1.00	1.00	-1.00	150	0.0056	6123	0.0048	18.5	0.0013	70.5
4	35	38	-1.00	1.00	-1.00	-1.00	-1.00	1.00	1.00	180	0.0038	5038	0.0045	26.4	0.0009	68.9
4	25	39	-1.00	-1.00	-1.00	1.00	1.00	-1.00	1.00	165	0.0019	5345	0.0043	25.8	0.0008	69.0
4	9	40	-1.00	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	180	0.0058	5748	0.0045	25.9	0.0009	69.2
4	40	41	1.00	1.00	1.00	-1.00	-1.00	1.00	1.00	150	0.0051	6761	0.0048	29.5	0.0010	73.0
4	42	42	1.00	-1.00	-1.00	1.00	-1.00	1.00	-1.00	150	0.0026	7376	0.0047	29.8	0.0011	73.8
4	15	43	-1.00	1.00	1.00	1.00	-1.00	-1.00	-1.00	180	0.0052	6401	0.0047	25.8	0.0010	69.8
4	7	44	-1.00	1.00	1.00	-1.00	-1.00	-1.00	1.00	210	0.0057	5755	0.0047	25.1	0.0011	69.4
4	59	45	-1.00	1.00	-1.00	1.00	1.00	1.00	1.00	240	0.0053	6646	0.0045	24.7	0.0010	69.0
4	2	46	1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	240	0.0068	6316	0.0049	28.3	0.0015	72.8
4	27	47	-1.00	1.00	-1.00	1.00	1.00	-1.00	-1.00	150	0.0010	4085	0.0050	23.2	0.0008	67.6
4	8	48	1.00	1.00	1.00	-1.00	-1.00	-1.00	-1.00	180	0.0050	6329	0.0051	27.1	0.0009	71.9
4	18	49	1.00	-1.00	-1.00	-1.00	1.00	-1.00	1.00	195	0.0054	7564	0.0051	27.7	0.0011	74.1

Case	Std	Run	Factor 1 A: Inside Starting Temp Hi-Lo	Factor 2 B: Inside Starting Humidity Hi-Lo	Factor 3 C: Outside Airflow into Bldg Hi-Lo	Factor 4 D: ERV Supply Fan Speed Hi-Lo	Factor 5 E: ERV Exhaust Fan Speed Hi-Lo	Factor 6 F: Desiccant Regen Airflow Hi-Lo	Factor 7 G: Desiccant Regen Temp Hi-Lo	Response 1 Humidity Time Constant (Sec)	Response 2 Delta In-Out Humidity lb H_2O/lb Air (Start)	Response 3 A/C Power Actual Btu/hr (Average)	Response 4 Inside Humidity lb H_2O/lb Air (Final)	Response 5 Delta In-Out Temp °F (Final)	Response 6 Delta In-Out Humidity lb H_2O/lb Air (Final)	Response 7 Inside Temp °F (Final)
4	45	50	-1.00	-1.00	1.00	1.00	-1.00	1.00	-1.00	165	0.0033	6165	0.0047	23.8	0.0007	69.4
4	5	51	-1.00	-1.00	1.00	-1.00	-1.00	-1.00	-1.00	150	0.0015	5703	0.0047	24.0	0.0008	70.0
4	11	52	-1.00	1.00	-1.00	1.00	-1.00	-1.00	1.00	210	0.0049	5676	0.0052	24.4	0.0015	70.6
4	20	53	1.00	1.00	-1.00	-1.00	1.00	-1.00	-1.00	225	0.0075	6424	0.0057	28.0	0.0020	73.7
4	12	54	1.00	1.00	-1.00	1.00	-1.00	-1.00	-1.00	180	0.0069	7152	0.0054	26.6	0.0018	73.2
4	30	55	1.00	-1.00	1.00	1.00	1.00	-1.00	1.00	210	0.0055	7573	0.0052	26.1	0.0016	73.4
4	34	56	1.00	-1.00	-1.00	-1.00	-1.00	1.00	1.00	165	0.0054	7053	0.0050	26.6	0.0016	74.4
4	52	57	1.00	1.00	-1.00	-1.00	1.00	1.00	1.00	165	0.0039	6368	0.0052	26.2	0.0018	73.7
4	47	58	-1.00	1.00	1.00	1.00	-1.00	1.00	1.00	165	0.0044	5887	0.0048	23.1	0.0013	69.8
4	43	59	-1.00	1.00	-1.00	1.00	-1.00	1.00	-1.00	255	0.0067	5861	0.0051	23.0	0.0018	70.9
4	16	60	1.00	1.00	1.00	1.00	-1.00	-1.00	1.00	180	0.0073	7408	0.0054	26.3	0.0021	73.9
4	4	61	1.00	1.00	-1.00	-1.00	-1.00	-1.00	1.00	270	0.0090	6932	0.0060	26.4	0.0028	74.4
4	54	62	1.00	-1.00	1.00	-1.00	1.00	1.00	1.00	195	0.0036	7030	0.0052	26.1	0.0020	74.4
4	55	63	-1.00	1.00	1.00	-1.00	1.00	1.00	1.00	150	0.0034	6210	0.0047	22.5	0.0017	70.9
4	53	64	-1.00	-1.00	1.00	-1.00	1.00	1.00	-1.00	180	0.0036	6763	0.0047	21.7	0.0019	70.5

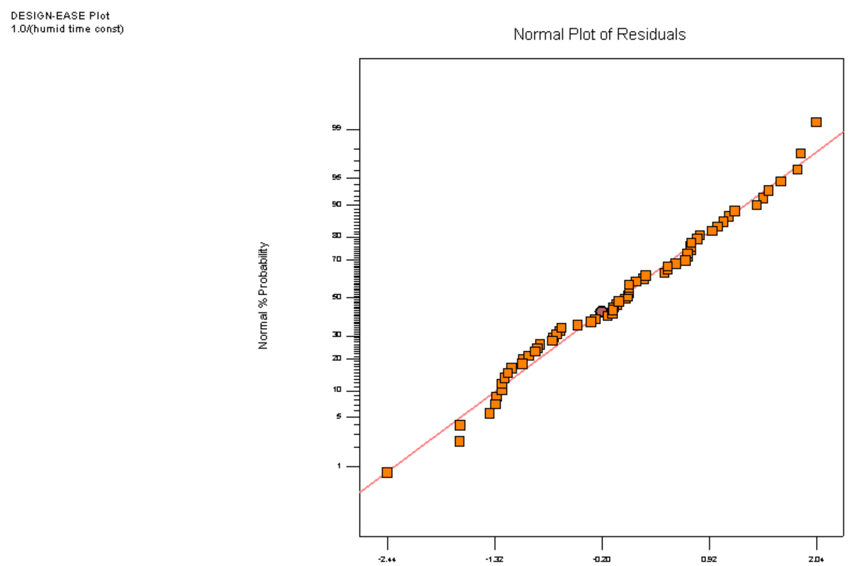

Figure 49. Normal plot of residuals for humidity time constant (Response 1)

Normally, if there is nonconstant variance, a variance-stabilizing transformation is applied, and then the analysis of variance analysis is run again on the transformed data. In these cases, the analysis of variance analysis results apply to the transformed data. Much work has been done historically on how to select a transformation. Box and Cox have developed a method based on maximum likelihood analysis for the transformation parameter λ estimated simultaneously with other model parameters such as the overall mean and treatment effects.[5]

The Box-Cox plot of the data for Response 1 indicates that an inverse transform of the data is of assistance in interpreting the data. This transform was done on the data prior to modeling.

The Box Cox plot can be used to find a power transformation for the response data. Usually, data transformations are characterized with a power function. σ (standard deviation) is a function of μ (mean) and α (power) . With $\lambda = 1 - \alpha$, if σ for an observation is proportional to the μ to some power α, then transforming the observation by the $1 - \alpha$ power gives a scale satisfying the equal variance requirement of the statistical model. For $1 - \alpha = -1$, an inverse transform is used. This transform is useful in cases in which a response is a rate (such as gallons per minute yielding minutes per gallon) and the standard deviation increases with the square of the mean (power of 2).

The lowest point on the Box Cox plot represents the value of λ that gives the minimum residual sum of squares in the transformed model. The Box-Cox plot for this case can be found in Appendix F. The plot shows the minimum λ value as well as the 95% confidence range.

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[5] Box, G.E.P; Cox, D.R. "An Analysis of Transformations." *Journal of the Royal Statistical Society*, B, Vol. 26, pp. 211-243. 1964.

As shown in figures 50 through 52, the humidity time constant is very sensitive to starting temperature for high air exchange rates. For high temperatures, the desiccant unit took much less time to reduce the humidity than at lower or nominal temperatures (remembering that the inverse of the time constant is plotted). This indicates that heat in a combined CHP system should first be used for desiccant dehumidification and then for absorption cooling if the starting room temperature is high. If the room temperature is normal or low, there is no noticeable priority or sequence.

For low air exchange rates, the effect is less noticeable. There is a minimum path that can be seen from the graph for the minimum humidity time constant. (The Box-Cox plot did not indicate a transform for this data.) If the rate of decrease in humidity is an important design consideration for a particular application, then the CHP control system should attempt to follow the maximum path described in Figure 56 for normal or low starting temperature cases.

The exact choice of a scheme is part of the total optimization described in Task 4. The information provided by these tests should be included as constraints or directly as terms in the index of performance in the total optimization process.

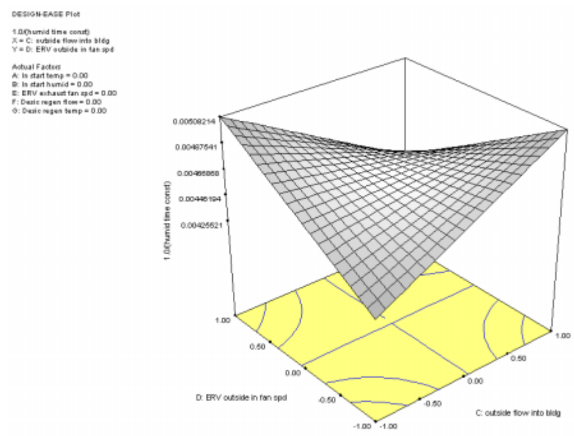


Figure 50. Results for humidity time constant (Response 1) with nominal starting temperature

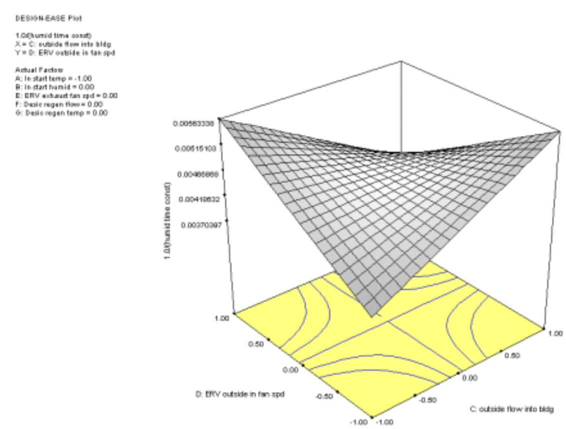


Figure 51. Results for humidity time constant (Response 1) with low starting temperature

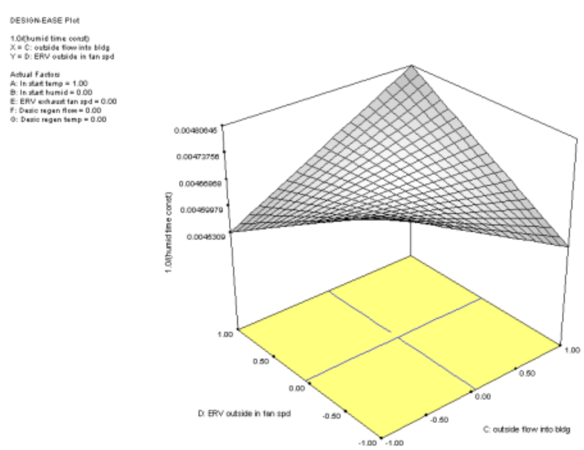


Figure 52. Results for humidity time constant (Response 1) with high starting temperature

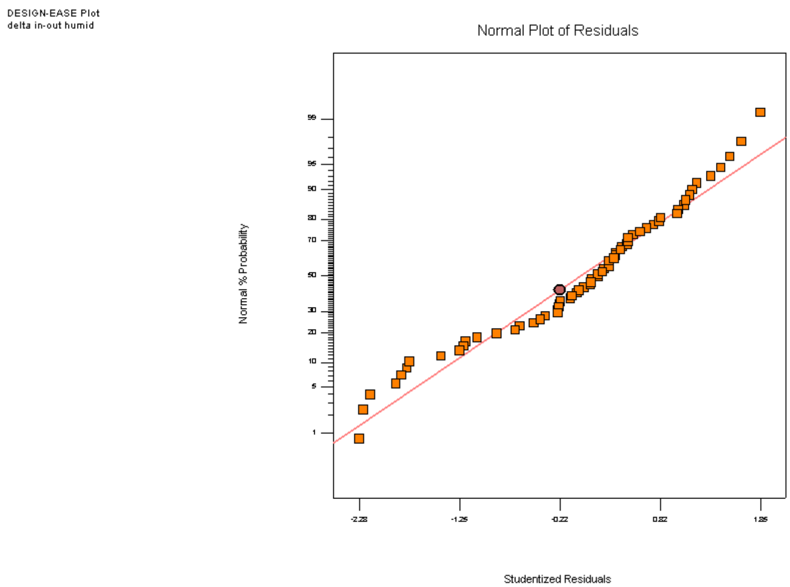


Figure 53. Normal plot of residuals for delta in-out humidity (Response 2)

Figures 54 through 56 show that Response 2 (the difference of inside and outside humidity) shows particular sensitivity to the rate of introduction of outside air through the ERV. This sensitivity is attributable to the function of the ERV in attempting to balance temperature and humidity levels for the entering air flow.

By looking at the results from Response 1, it can also be noted that the humidity time constant shows little sensitivity to the rate of introduction of outside air through the ERV. This is because the air thus introduced fairly well matches the humidity in the building, and hence the desiccant unit doesn’t have to remove the water contained in the incoming air.

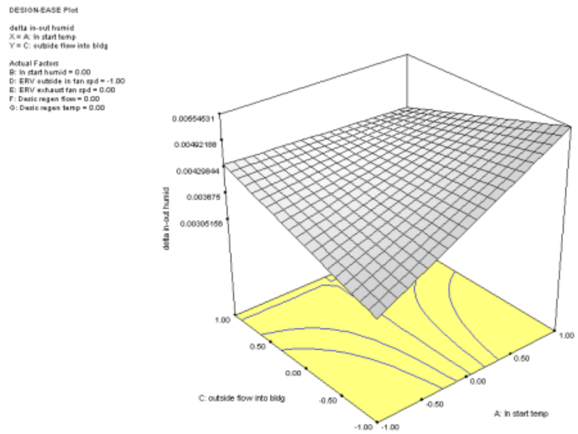


Figure 54. Results for delta in-out humidity with ERV outside in fan speed at low level

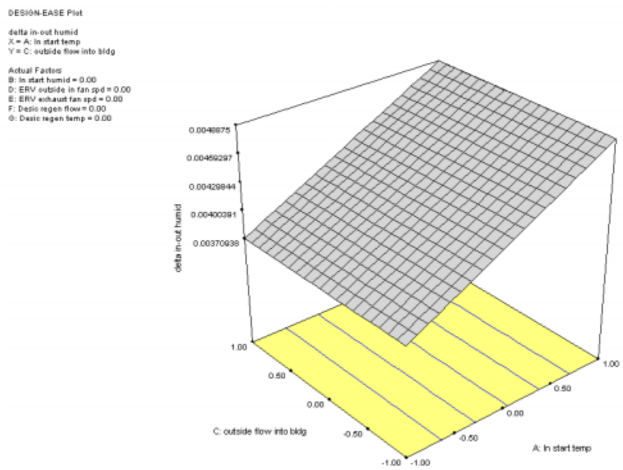


Figure 55. Results for delta in-out humidity with ERV outside in fan speed at zero level

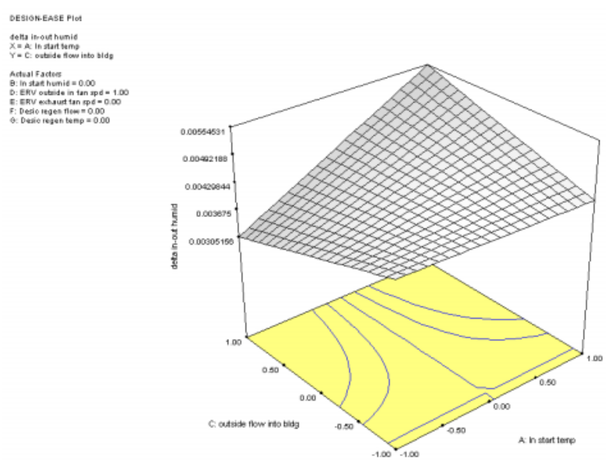


Figure 56. Results for delta in-out humidity with ERV outside in fan speed at high level

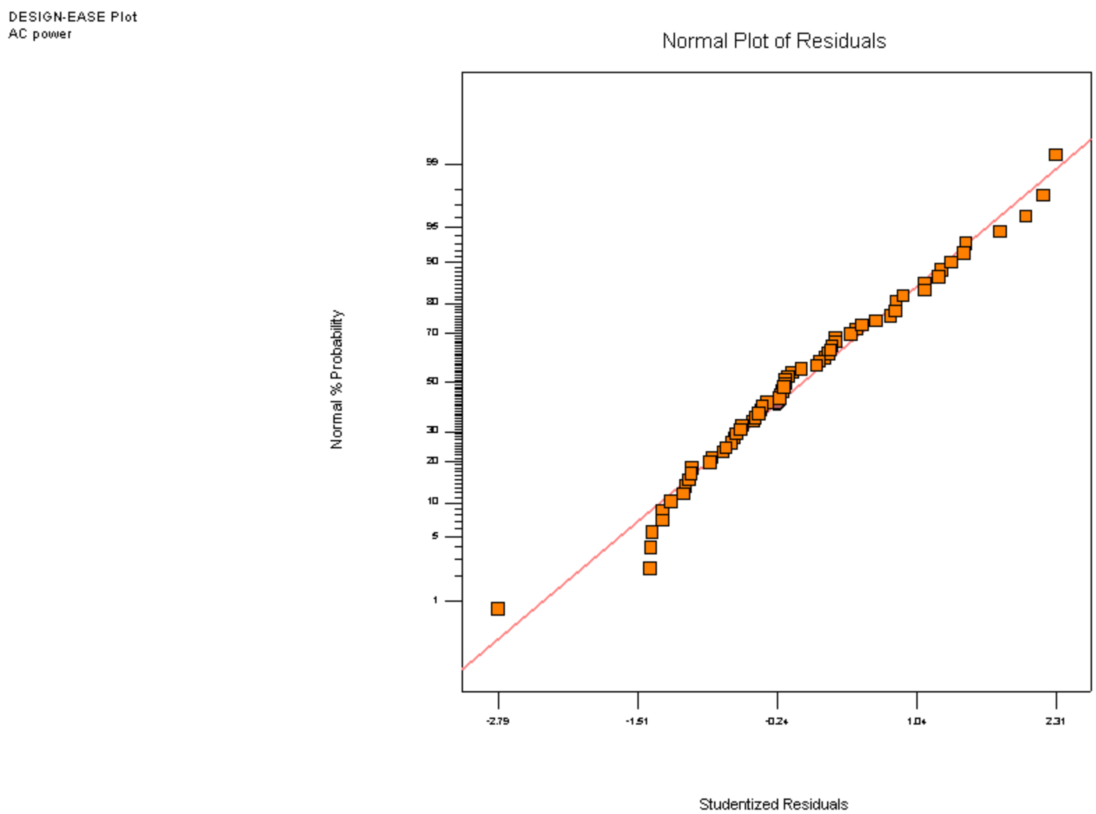


Figure 57. Normal plot of residuals for air conditioner power (Response 3)

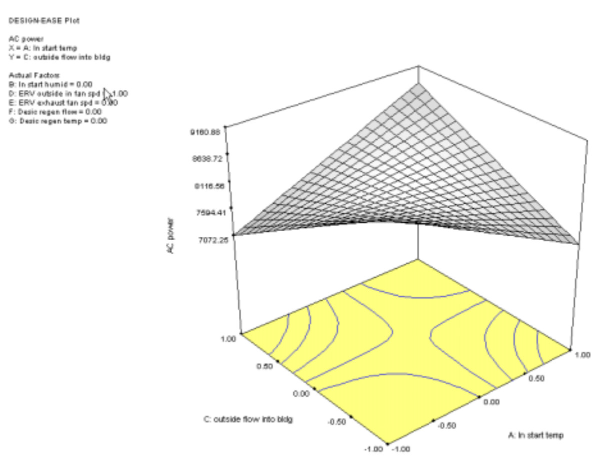


Figure 58. Results for air conditioner power with ERV outside air in fan speed at low level

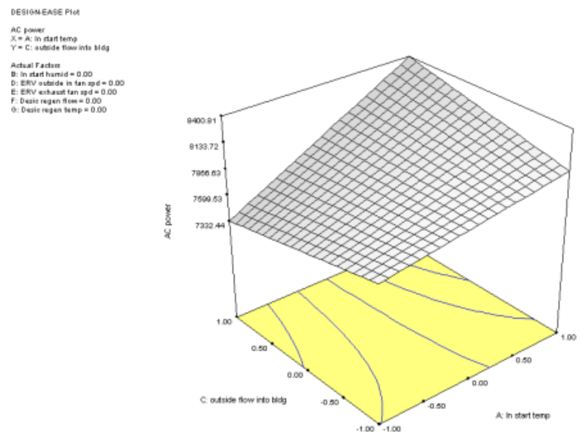


Figure 59. Results for air conditioner power with ERV outside air in fan speed at zero level

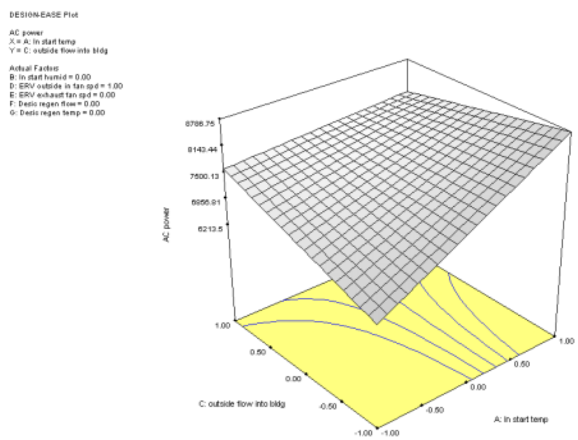


Figure 60. Results for air conditioner power with ERV outside air in fan speed at high level

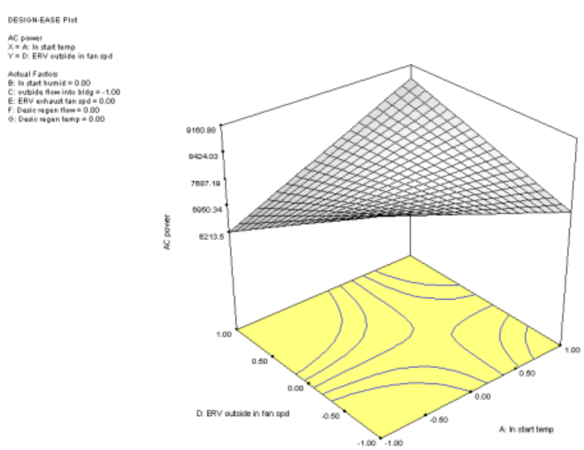


Figure 61. Results for air conditioner power with outside air in fan speed at low level

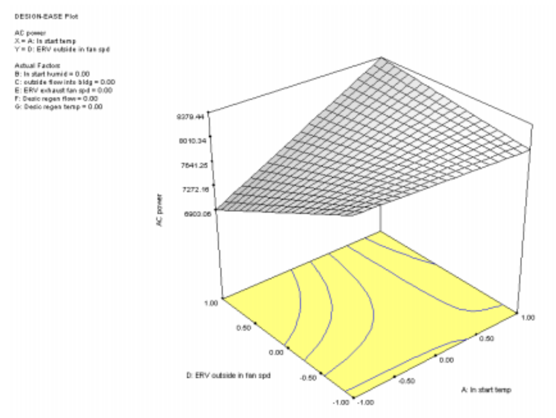


Figure 62. Results for air conditioner power with outside air in fan speed at zero level

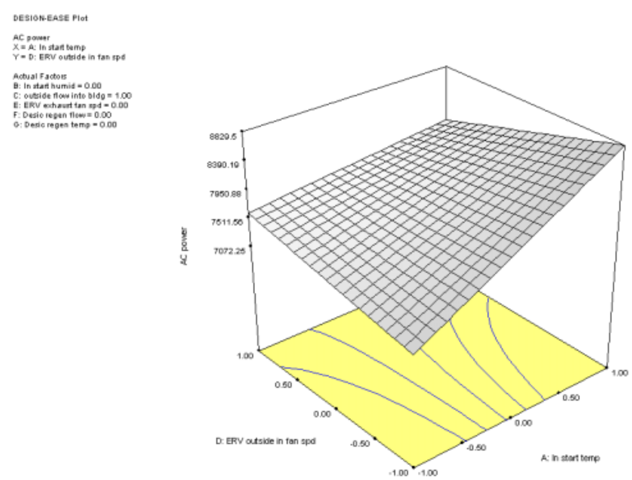


Figure 63. Results for air conditioner power with outside air in fan speed at high level

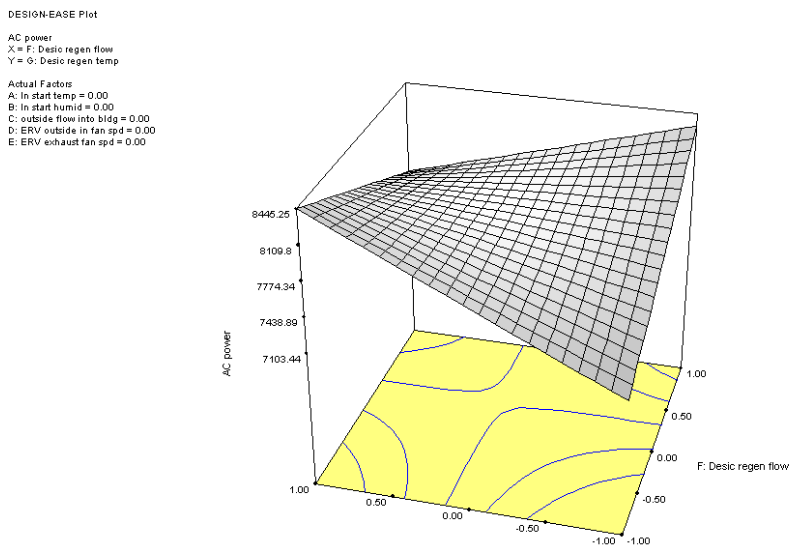


Figure 64. Results for air conditioner power

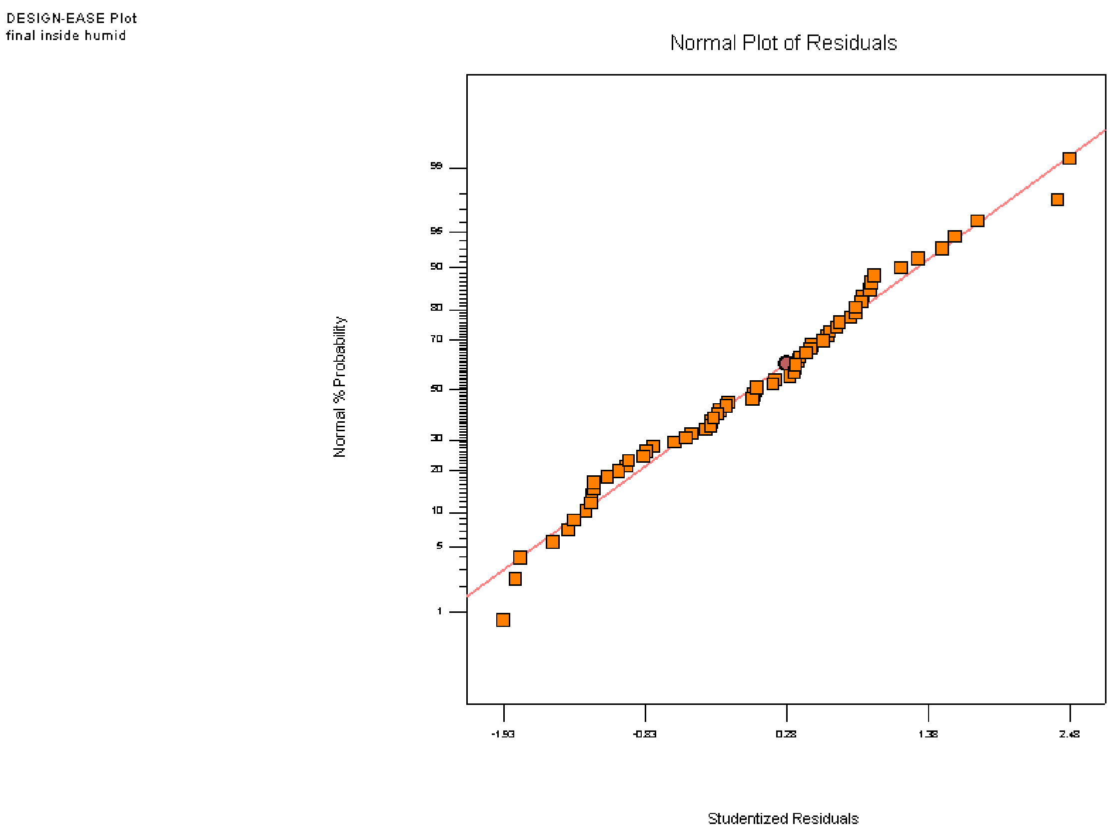


Figure 65. Normal plot of residuals for final inside humidity

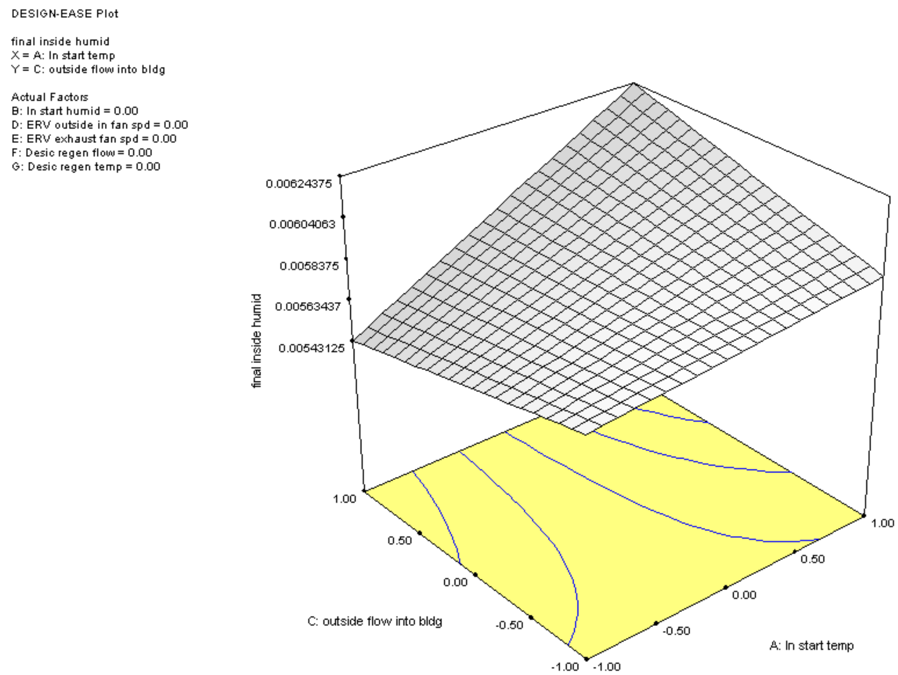


Figure 66. Results for final inside humidity

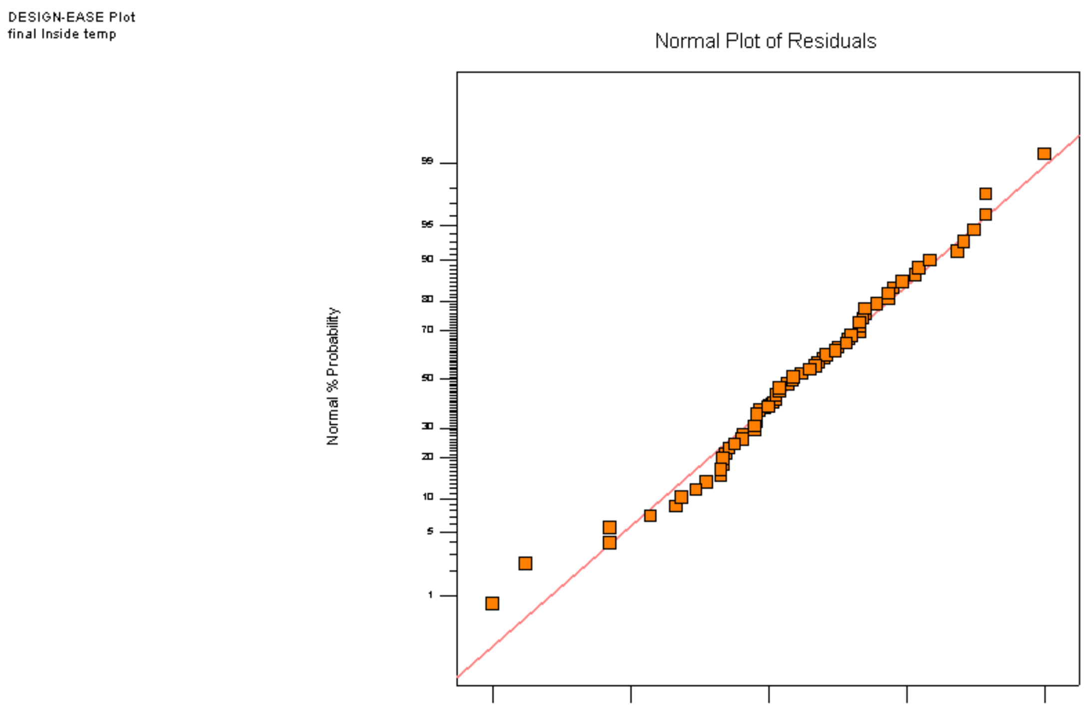


Figure 67. Normal plot of residuals for final inside temperature

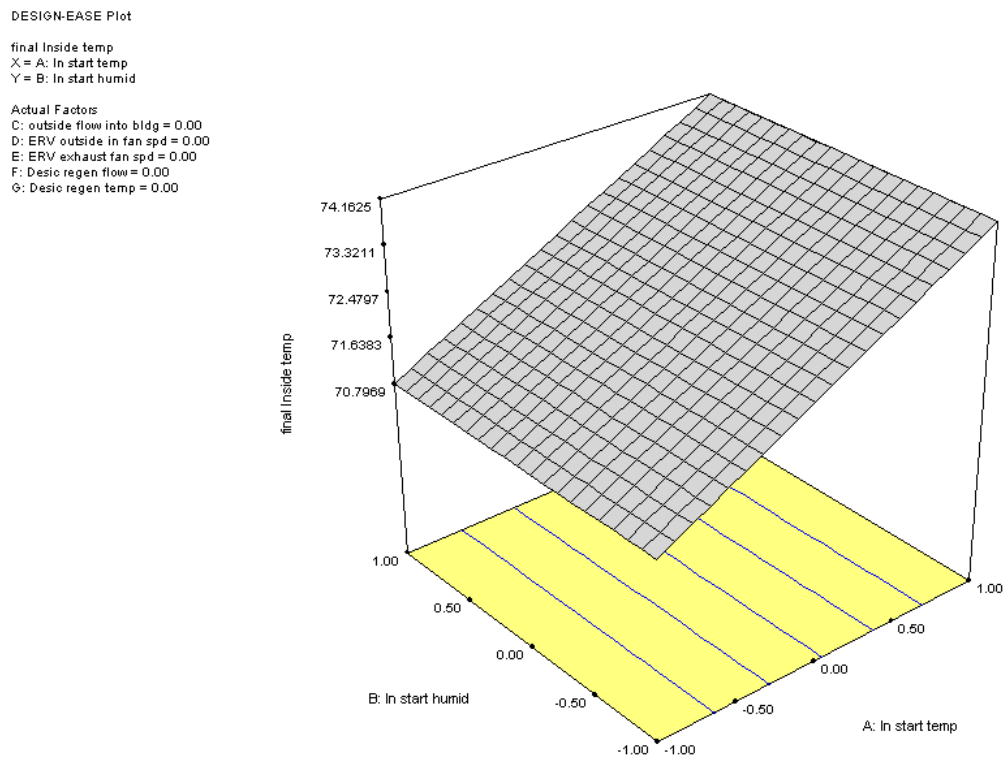


Figure 68. Results for final inside temperature

4.1.3 Warehouse Site

This test site is also located in Gary, Indiana. This site provides an opportunity to investigate issues associated with the use of CHP for warehouse applications. The warehouse is divided into two sections that can be separated for tests.

A building model was constructed for the site using the same basic model described for the office. Initially, half the building was modeled, and preliminary benchmarking of the model was performed. The building is separated into two parts with a large, open doorway (30 ft by 20 ft) between them. For the initial tests, this doorway was covered. Later, the doorway was opened. A CHP system with a 30-kW microturbine was used to supply electricity and heat to the building, and the absorber system previously described was used to supply cool air to the building.

Figures 69 through 72 show the devices. In addition to these devices, large floor fans were used to circulate the air for a portion of the testing.

Figure 69. Cooling heat exchanger with instrumentation for warehouse

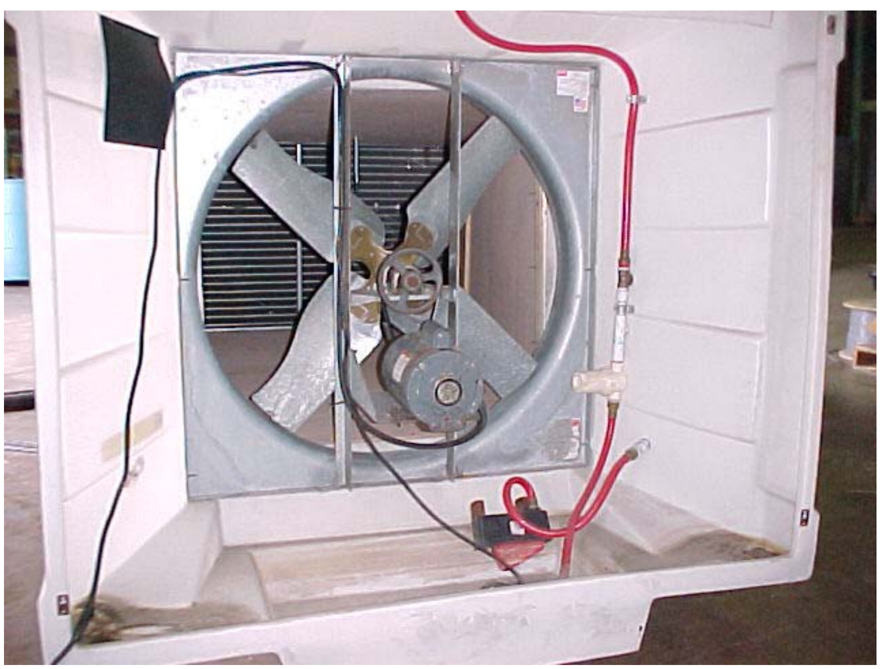


Figure 70. Fan for cooling heat exchanger

Figure 71. Heating heat exchanger for warehouse with instrumentation

Figure 72. Microturbine and heat exchanger for warehouse

Data were gathered for the operation of the system in cold and warm weather, and the data were then used to benchmark the model. Next, the model was used to assess the predicted effectiveness of the CHP application for a range of weather conditions.

Table 16 and Table 17 show a sample of the data collected during the heating function for single and dual zones. Table 18 and Table 19 show a sample of the data collected during the cooling function for single and dual zones. Additional data can be found in Appendix G.

Table 16. Warehouse Data Sample for Single Zone

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
0:00:00	125.0	139.9	105258	12540	92718	54.2	78.7	84.6	32.4
0:01:00	124.7	139.6	105329	12027	93302	54.2	78.5	84.6	32.4
0:02:00	124.7	139.6	104820	11730	93090	54.3	78.2	84.6	32.3
0:03:00	124.5	139.6	106404	11596	94807	54.5	78.1	84.6	32.3
0:04:00	124.6	139.5	105244	11346	93898	54.5	77.6	84.6	32.2
0:05:00	124.5	139.6	106651	11823	94828	54.4	76.9	84.6	32.2
0:06:00	124.6	139.7	106941	12027	94914	54.3	76.6	84.6	32.2
0:07:00	124.6	140.0	108623	12397	96227	54.4	76.4	84.7	32.2
0:08:00	124.8	140.3	109670	12832	96838	54.4	76.3	84.7	32.2
0:09:00	124.9	140.2	108348	12678	95670	54.4	76.2	84.6	32.2
0:10:00	125.0	140.2	108023	12510	95512	54.5	76.0	84.6	32.2
0:11:00	125.0	140.4	109083	12908	96175	54.4	75.8	84.6	32.2
0:12:00	125.1	140.4	107973	13321	94652	54.1	75.3	84.5	32.2
0:13:00	125.2	140.4	107605	13497	94108	54.1	75.3	84.5	32.1
0:14:00	125.2	140.4	107676	13840	93836	53.9	75.1	84.5	32.1
0:15:00	125.1	140.5	108843	14007	94836	53.9	75.1	84.5	32.1
0:16:00	125.2	140.5	108553	14097	94456	53.8	75.1	84.6	32.1
0:17:00	125.2	140.1	105986	13741	92245	53.6	75.1	84.6	32.1
0:18:00	125.0	139.7	103696	13258	90438	53.5	75.1	84.6	32.1
0:19:00	124.7	139.4	104099	13150	90948	53.3	74.9	84.6	32.1
0:20:00	124.4	139.3	105046	12989	92057	53.2	75.1	84.6	32.1
0:21:00	124.2	139.1	105421	12513	92908	53.4	75.6	84.6	32.1
0:22:00	124.4	139.6	107874	12981	94893	53.6	76.0	84.6	32.0
0:23:00	124.5	139.7	107344	12829	94515	53.8	76.3	84.6	32.0
0:24:00	124.6	139.8	107535	12832	94703	53.9	76.3	84.5	32.0
0:25:00	124.7	140.1	109189	13146	96043	54.0	76.3	84.5	32.0
0:26:00	124.8	140.1	108058	13354	94704	53.8	75.7	84.5	32.0
0:27:00	124.9	140.0	106821	13509	93311	53.7	75.2	84.5	32.1
0:28:00	124.8	140.2	108532	14235	94296	53.4	74.8	84.5	32.0
0:29:00	125.0	140.2	107436	14605	92831	53.2	74.7	84.4	32.0
0:30:00	124.8	140.2	109090	14897	94193	53.0	74.7	84.5	32.1
0:31:00	124.9	140.3	108779	15157	93622	52.9	75.1	84.5	32.0
0:32:00	125.0	140.3	107931	15365	92566	52.8	75.3	84.5	32.0
0:33:00	125.2	140.1	105583	15174	90410	52.7	75.5	84.5	32.0
0:34:00	125.1	140.3	107584	15607	91977	52.6	75.5	84.5	32.0
0:35:00	124.9	140.1	107047	15283	91764	52.6	75.9	84.5	31.9
0:36:00	125.0	140.1	107075	15502	91573	52.5	76.0	84.5	31.9

Table 17. Warehouse Data Sample for Dual Zones

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
0:00:00	132.1	115.8	115278	49.7	44.9	75.5	27.8
0:01:00	132.4	115.8	116819	49.7	44.5	75.5	27.8
0:02:00	131.4	115.7	110761	49.7	44.4	75.5	27.7
0:03:00	129.8	114.0	111561	49.7	44.0	75.5	27.8
0:04:00	130.5	114.7	112042	49.7	44.0	75.5	27.7
0:05:00	130.8	114.4	115816	49.7	43.6	75.6	27.7
0:06:00	129.7	113.8	112413	49.7	43.6	75.6	27.7
0:07:00	130.8	114.4	116265	49.7	43.8	75.6	27.7
0:08:00	131.2	115.3	112438	49.7	44.2	75.6	27.7
0:09:00	130.7	114.9	111679	49.7	44.4	75.6	27.7
0:10:00	131.8	114.6	121409	49.8	44.5	75.6	27.7
0:11:00	132.2	115.3	119438	49.7	44.7	75.6	27.7
0:12:00	131.6	115.2	115865	49.7	44.0	75.6	27.7
0:13:00	131.1	115.1	112844	49.7	43.3	75.6	27.7
0:14:00	131.1	114.8	115097	49.7	42.7	75.6	27.7
0:15:00	131.8	115.1	118257	49.7	42.1	75.6	27.7
0:16:00	130.3	114.8	109661	49.8	41.8	75.5	27.7
0:17:00	130.9	114.6	114962	49.8	42.1	75.5	27.7
0:18:00	130.6	114.7	112535	49.8	42.6	75.5	27.7
0:19:00	130.7	114.8	112580	49.7	42.8	75.5	27.7
0:20:00	130.2	114.6	110025	49.7	43.1	75.5	27.7
0:21:00	130.6	114.7	112535	49.7	43.6	75.5	27.7
0:22:00	130.3	114.4	111867	49.7	43.5	75.5	27.7
0:23:00	129.6	114.1	109190	49.7	43.1	75.5	27.7
0:24:00	131.2	114.9	114692	49.7	42.6	75.5	27.6
0:25:00	131.2	114.8	116043	49.7	42.4	75.5	27.7
0:26:00	130.8	114.4	116265	49.7	42.4	75.5	27.7
0:27:00	131.4	115.1	115774	49.7	42.7	75.5	27.7
0:28:00	131.3	115.1	114782	49.7	42.8	75.5	27.7
0:29:00	131.1	115.1	113295	49.7	43.2	75.5	27.6
0:30:00	131.1	114.6	116447	49.7	43.5	75.5	27.7
0:31:00	131.3	115.6	111170	49.7	43.6	75.5	27.7
0:32:00	131.8	115.3	116452	49.8	43.4	75.5	27.7
0:33:00	129.9	114.5	108955	49.8	43.3	75.5	27.6
0:34:00	129.1	113.9	108040	49.8	43.2	75.5	27.6
0:35:00	129.8	113.7	113352	49.8	43.3	75.5	27.6
0:36:00	129.3	113.7	110363	49.7	43.7	75.5	27.6

Table 18. Warehouse Sample Cooling Data (Single Zone)

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity % RH	N. Zone Temp °F	N. Zone Humidity % RH
13:10:00	66.1	67.9	24.4	22119	75.2	58.3	79.0	63.8
13:11:00	62.3	63.8	24.0	18491	75.2	58.6	79.0	63.8
13:12:00	58.7	60.2	23.9	18151	75.3	58.9	79.0	63.8
13:13:00	55.6	56.9	23.7	15453	75.4	58.5	79.0	63.8
13:14:00	53.4	54.2	23.9	10643	75.3	58.4	79.0	63.7
13:15:00	51.9	52.9	23.8	11478	75.5	58.6	79.0	63.3
13:16:00	49.6	50.6	27.5	13858	75.7	58.2	78.9	63.1
13:17:00	47.6	56.9	27.5	128236	75.7	58.7	78.9	62.5
13:18:00	49.1	58.2	27.6	126911	75.3	58.3	78.8	62.7
13:19:00	50.2	59.4	27.6	127366	75.2	58.6	78.8	62.7
13:20:00	52.0	60.1	27.6	113353	75.4	58.9	78.7	62.2
13:21:00	53.0	60.9	27.4	108846	75.2	59.0	78.7	62.0
13:22:00	53.1	60.8	27.9	108312	75.3	59.6	78.7	62.0
13:23:00	52.8	60.7	27.8	111004	75.0	59.4	78.7	61.8
13:24:00	52.0	60.2	27.8	114143	75.0	59.4	78.6	61.7
13:25:00	51.3	59.6	27.7	116412	75.0	59.7	78.5	61.4
13:26:00	51.0	59.2	27.7	115325	75.1	60.1	78.5	61.5
13:27:00	51.0	59.1	27.7	113243	75.0	59.6	78.5	61.4
13:28:00	51.9	59.4	27.8	104825	75.0	59.3	78.5	61.3
13:29:00	51.9	59.5	27.8	107337	74.9	59.8	78.5	61.1
13:30:00	51.8	59.4	27.7	107125	74.3	60.3	78.5	61.0
13:31:00	51.1	59.0	27.7	110375	74.2	60.7	78.4	60.7
13:32:00	50.2	58.4	27.7	114287	74.3	61.6	78.4	60.6
13:33:00	50.1	58.0	27.8	110987	74.7	62.2	78.4	60.6
13:34:00	51.2	58.5	27.7	101890	74.9	61.0	78.4	60.4
13:35:00	51.0	58.5	27.8	105279	74.9	60.3	78.3	60.3
13:36:00	50.8	58.4	27.7	105389	74.9	60.1	78.3	60.2
13:37:00	50.2	58.0	27.7	108186	75.0	60.4	78.2	60.1
13:38:00	49.5	57.5	27.7	111546	75.0	61.2	78.2	59.9
13:39:00	49.4	57.1	27.4	106161	74.8	61.3	78.2	59.8
13:40:00	50.5	57.7	27.7	100809	74.8	61.5	78.2	59.8
13:41:00	50.3	57.6	27.7	102793	75.2	60.8	78.2	59.6
13:42:00	50.1	57.5	27.7	103961	74.9	60.4	78.2	59.6
13:43:00	49.6	57.1	27.7	105725	74.9	61.0	78.2	59.4
13:44:00	48.8	56.6	27.7	109179	74.4	61.1	78.2	59.3
13:45:00	49.8	56.8	27.8	98128	73.8	61.4	78.2	59.2
13:46:00	49.8	57.1	27.8	102387	73.7	62.3	78.2	59.2

Table 19. Warehouse Sample Cooling Data (Dual Zone)

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
14:21:00	60.7	61.8	28.2	15080	57.9	22.3	73.7	25.7
14:22:00	59.7	61.1	28.2	19285	57.5	22.4	73.6	25.7
14:23:00	57.6	58.3	28.3	9608	57.1	22.4	73.6	25.7
14:24:00	55.7	56.7	28.3	14254	57.1	22.3	73.6	25.8
14:25:00	54.0	54.9	28.2	13410	57.5	21.9	73.6	25.8
14:26:00	52.8	56.1	28.2	46362	58.0	21.6	73.5	25.8
14:27:00	52.6	57.1	28.2	64130	58.0	21.5	73.5	25.8
14:28:00	52.2	57.3	28.1	72276	58.1	21.2	73.5	25.9
14:29:00	52.3	56.9	28.2	66850	58.0	21.3	73.4	25.9
14:30:00	52.8	57.4	28.1	64687	58.1	21.2	73.4	25.9
14:31:00	52.0	57.0	28.1	70448	58.1	21.5	73.3	25.9
14:32:00	51.2	56.3	28.1	71993	58.3	20.8	73.3	26.0
14:33:00	51.2	56.0	28.1	68332	58.2	21.0	73.2	26.0
14:34:00	51.3	56.3	28.0	70726	58.0	20.8	73.2	26.2
14:35:00	50.4	55.6	28.0	73504	58.2	20.8	73.1	26.2
14:36:00	49.7	55.1	28.0	76443	58.3	20.5	73.1	26.2
14:37:00	49.7	54.8	28.0	72348	58.3	20.4	73.0	26.2
14:38:00	49.5	54.9	27.9	76389	58.5	20.6	73.0	26.3
14:39:00	48.9	54.3	27.9	75261	58.6	20.7	73.0	26.3
14:40:00	48.2	53.8	27.9	78543	59.1	20.6	72.9	26.3
14:41:00	48.3	53.6	27.9	75183	58.6	20.1	72.9	26.4
14:42:00	48.2	53.7	27.9	78011	58.4	20.6	72.9	26.5
14:43:00	47.8	53.3	27.8	77101	58.5	20.9	72.8	26.4
14:44:00	47.3	52.9	27.9	79073	59.0	20.6	72.8	26.5
14:45:00	47.7	53.0	27.9	75034	58.8	19.6	72.8	26.5
14:46:00	47.6	53.2	27.8	78729	59.0	19.2	72.7	26.5
14:47:00	47.3	52.9	27.8	78245	59.2	19.5	72.7	26.5
14:48:00	47.0	52.5	27.9	77275	59.4	19.5	72.6	26.5
14:49:00	47.5	52.9	27.8	74969	59.4	19.3	72.6	26.5
14:50:00	47.2	52.8	27.8	78931	59.5	19.4	72.6	26.7
14:51:00	47.1	52.7	27.8	78757	59.2	19.5	72.6	26.7
14:52:00	47.3	52.6	27.9	74833	59.3	19.3	72.6	26.7
14:53:00	47.6	53.0	27.8	75447	59.4	19.0	72.5	26.7
14:54:00	47.2	52.7	27.8	77077	59.7	19.2	72.4	26.7
14:55:00	46.9	52.5	27.8	78130	59.8	19.0	72.4	26.7
14:56:00	47.4	52.5	27.8	72393	59.7	18.5	72.4	26.8
14:57:00	47.2	52.8	27.7	78488	59.5	18.4	72.3	26.8

4.2 Emissions

CHP holds promise of reducing environmentally harmful emissions through its high efficiency. Emissions information was calculated from the Gary test sites based on previous and current test information. Figure 73 shows the emissions for various power levels. Table 20 is the data for this figure. Figure 74 is the emissions over a period of time. Table 21 is the data for this figure.

As can be seen from Figure 73 and Figure 74, the nitrogen oxide (NO_X) emissions are nonlinear, with a peak occurring below 18 kW output. The carbon dioxide (CO_2) emissions are more constant and tend to follow the power level as would be expected because of a direct relation to the volume of natural gas consumed. There seems to be little dependence on ambient temperature. Factors such as gas supply pressure will also influence the efficiency of the unit, but once the losses are taken into account, the net effect on the emissions should be the same.

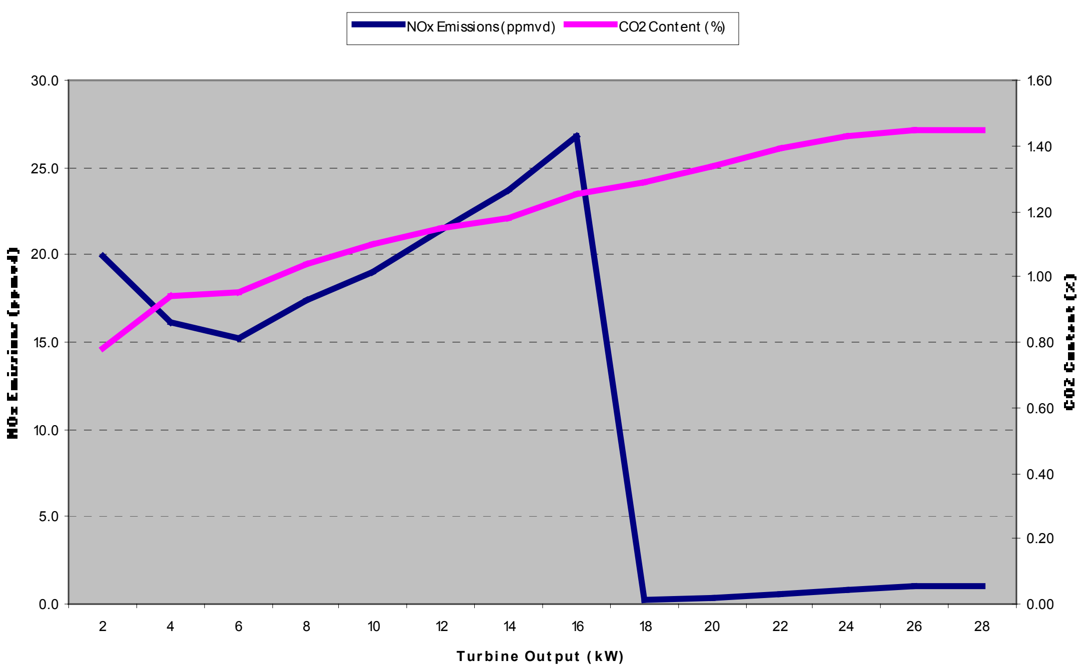


Figure 73. Emissions as a function of power level

Table 20. Emissions Versus Power Level

Power Level (kW)	NO_x Emissions (ppmvd)	CO_2 Content (%)
2	19.9	0.78
4	16.2	0.94
6	15.2	0.95
8	17.4	1.04
10	19.0	1.10
12	21.4	1.15
14	23.7	1.18
16	26.8	1.25
18	0.2	1.29
20	0.4	1.34
22	0.6	1.39
24	0.8	1.43
26	1.0	1.45
28	1.0	1.45

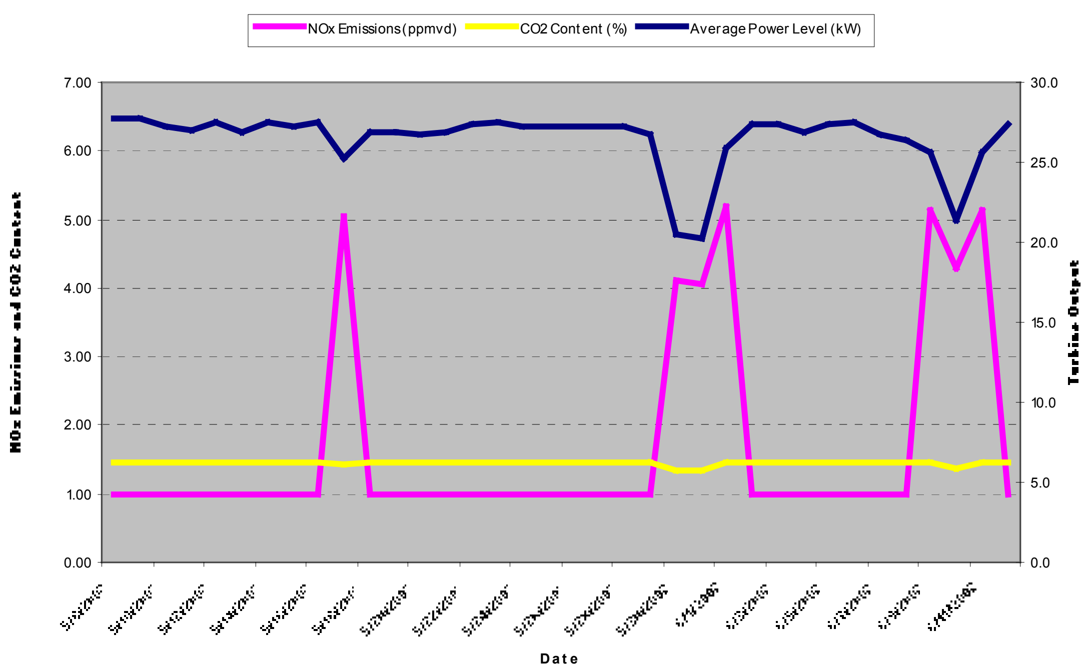


Figure 74. Emissions versus time

Table 21. Emissions Versus Time

Date	Average Power Level (kW)	NO_x Emissions (ppmvd)	CO_2 Content (%)
5/8/2002	27.7	1.00	1.450
5/9/2002	27.7	1.00	1.450
5/10/2002	27.3	1.00	1.450
5/11/2002	27.0	1.00	1.450
5/12/2002	27.5	1.00	1.450
5/13/2002	26.9	1.00	1.450
5/14/2002	27.5	1.00	1.450
5/15/2002	27.3	1.00	1.450
5/16/2002	27.5	1.00	1.450
5/17/2002	25.2	5.04	1.442
5/18/2002	26.9	1.00	1.450
5/19/2002	26.9	1.00	1.450
5/20/2002	26.8	1.00	1.450
5/21/2002	26.9	1.00	1.450
5/22/2002	27.4	1.00	1.450
5/23/2002	27.5	1.00	1.450
5/24/2002	27.3	1.00	1.450
5/25/2002	27.3	1.00	1.450
5/26/2002	27.3	1.00	1.450
5/27/2002	27.3	1.00	1.450
5/28/2002	27.2	1.00	1.450
5/29/2002	26.8	1.00	1.450
5/30/2002	20.5	4.10	1.353
5/31/2002	20.3	4.06	1.348
6/1/2002	25.9	5.18	1.449
6/2/2002	27.4	1.00	1.450
6/3/2002	27.4	1.00	1.450
6/4/2002	26.9	1.00	1.450
6/5/2002	27.4	1.00	1.450
6/6/2002	27.5	1.00	1.450
6/7/2002	26.8	1.00	1.450
6/8/2002	26.4	1.00	1.450
6/9/2002	25.6	5.12	1.446
6/10/2002	21.4	4.28	1.375
6/11/2002	25.6	5.12	1.446
6/12/2002	27.4	1.00	1.450

4.3 Building Model

Task 6 considers how CHP components interact with one another and the optimal choice of CHP systems for a particular application. In some cases, it was observed that the presence of one CHP device or system negated the need for another under various weather conditions. The use of a building model increased the applicability of the conclusions regarding the optimal CHP system because it allowed for consideration of possible weather conditions that could not practically be obtained experimentally. It also allowed for various sensitivity tests that could not be performed otherwise.

A small office building was chosen for this portion of the test to allow for quick and accurate comparison of building model data with experimental data. This office was in continual use and, hence, also provided experience with a daily-inhabited environment.

The building model was initially developed using MathCad from the Building Model E-book. This model was modified to accommodate the details of this application. This particular model was chosen because all the calculations were highly visible and self-documenting. The system also runs very quickly and thereby allows for rapid integration of experimental results into testing procedures.

One of the modifications to the model was to measure and include actual photometery data. Light measurements were taken with a meter that included an RS232 port that was connected to the data acquisition system. Figure 75 is a plot of the light energy for various locations during the day on July 17, 2002. Measurements for locations over each wall of the building and the roof were taken, and an average energy profile for a particular level of cloud cover and time of day was developed.

Figure 77 is a comparison of predicted and actual energy flow values for the office building for March 31, 2002 with corrected light energy data. There is reasonable comparison between the predicted and experimental data.

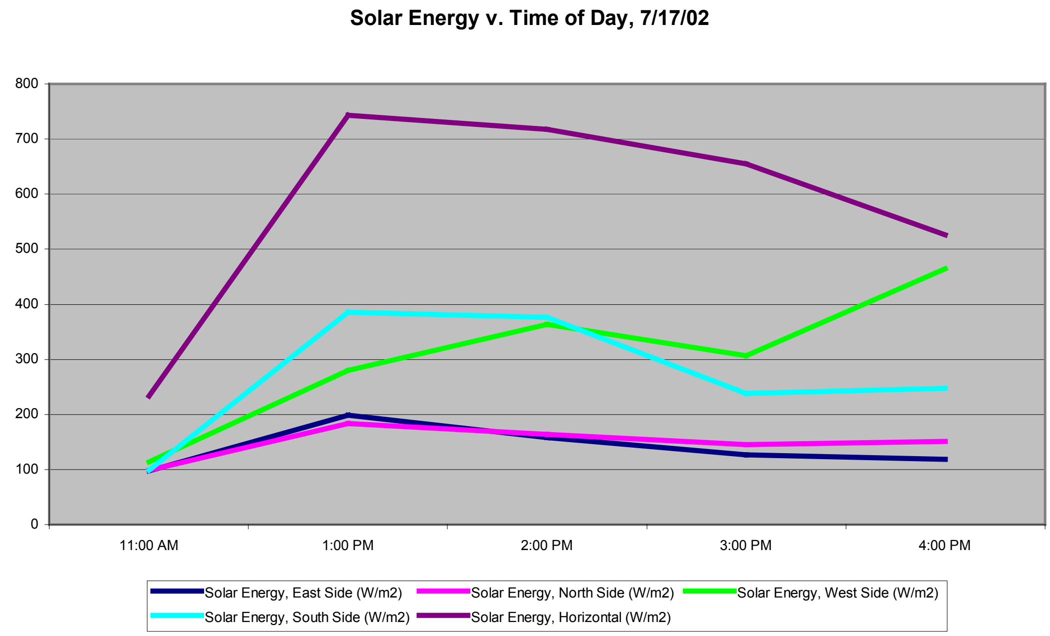


Figure 75. Light energy readings

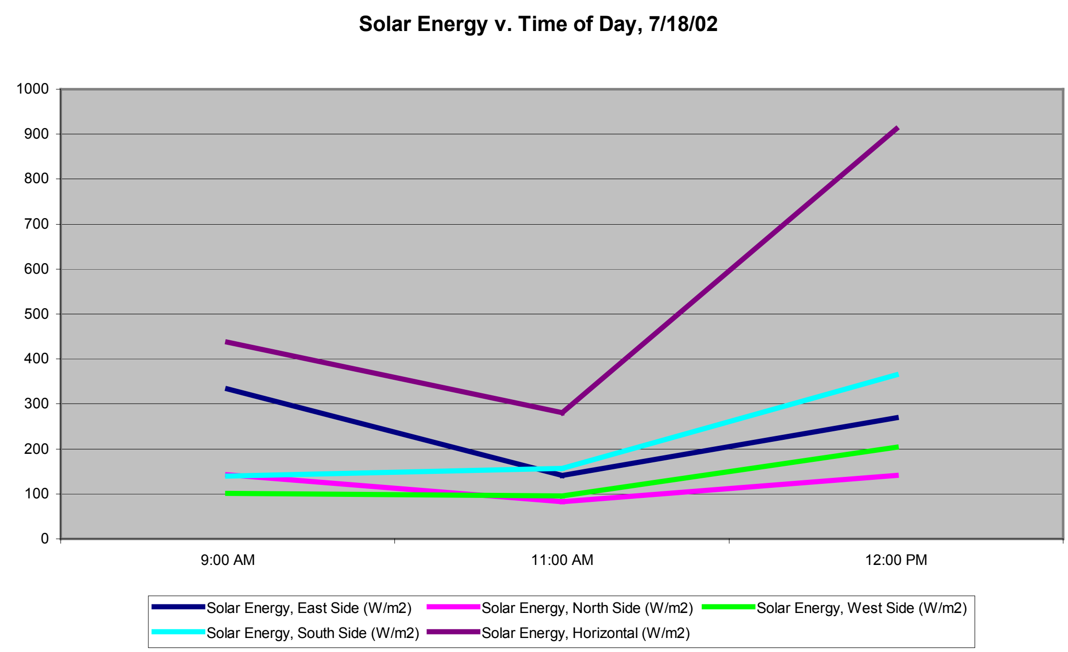


Figure 76. Solar energy readings versus time of day

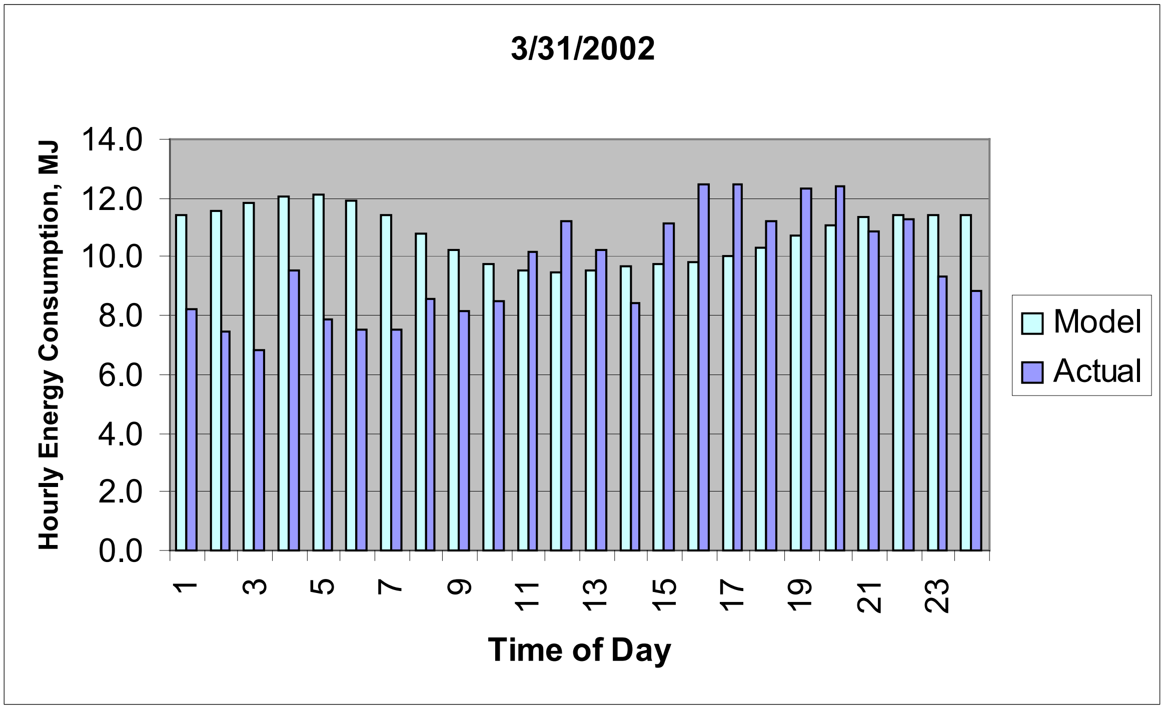


Figure 77. Model predicted versus experimental office building energy data for heating

Table 22. Office Building Heating Model Comparison Data

March 31, 2002	From Mathcad Model			From Data	
t	q	QM	Model	QA	Actual
0	3171.7	11.4	11.4	8.2	8.2
1	3214.8	11.6	23.0	7.5	15.7
2	3283.1	11.8	34.8	6.8	22.5
3	3343.9	12.0	46.8	9.6	32.1
4	3357.9	12.1	58.9	7.9	39.9
5	3299.3	11.9	70.8	7.5	47.5
6	3170.2	11.4	82.2	7.5	55.0
7	3000.8	10.8	93.0	8.6	63.6
8	2835.6	10.2	103.2	8.1	71.7
9	2713.3	9.8	113.0	8.5	80.3
10	2650.8	9.5	122.5	10.2	90.4
11	2640.0	9.5	132.1	11.2	101.6
12	2658.0	9.6	141.6	10.2	111.9
13	2682.4	9.7	151.3	8.4	120.3
14	2705.5	9.7	161.0	11.1	131.4
15	2735.3	9.8	170.9	12.5	143.9
16	2786.8	10.0	180.9	12.5	156.3
17	2868.5	10.3	191.2	11.2	167.6
18	2971.8	10.7	201.9	12.4	179.9
19	3073.7	11.1	213.0	12.4	192.3
20	3147.5	11.3	224.3	10.9	203.2
21	3179.3	11.4	235.8	11.3	214.5
22	3176.2	11.4	247.2	9.3	223.8
23	3163.9	11.4	258.6	8.9	232.7

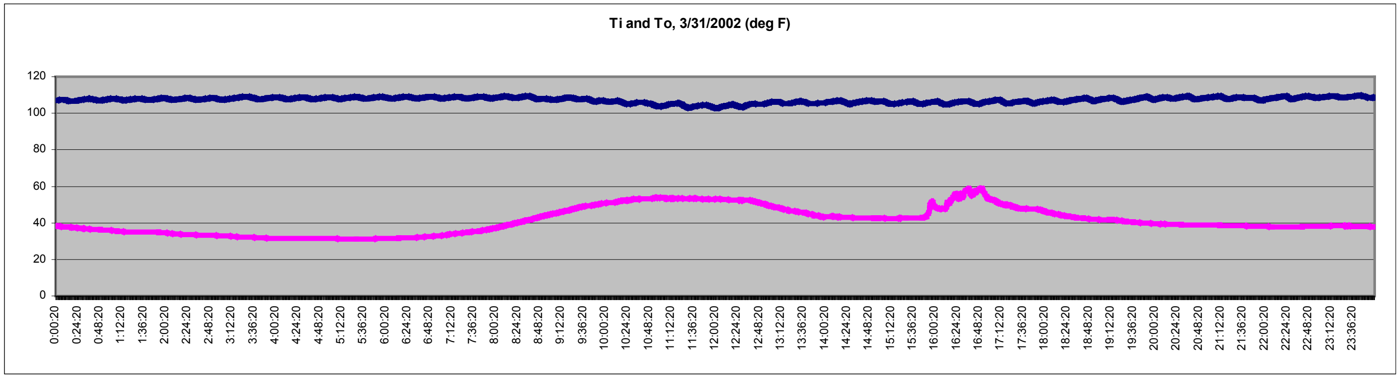


Figure 78. Recorded office building temperatures for heating model

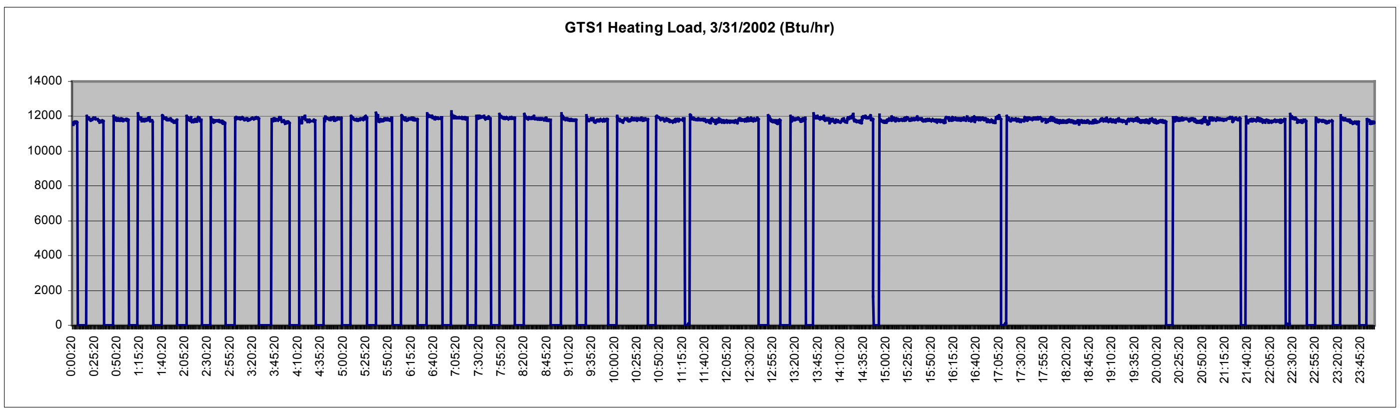


Figure 79. Recorded office building heating data

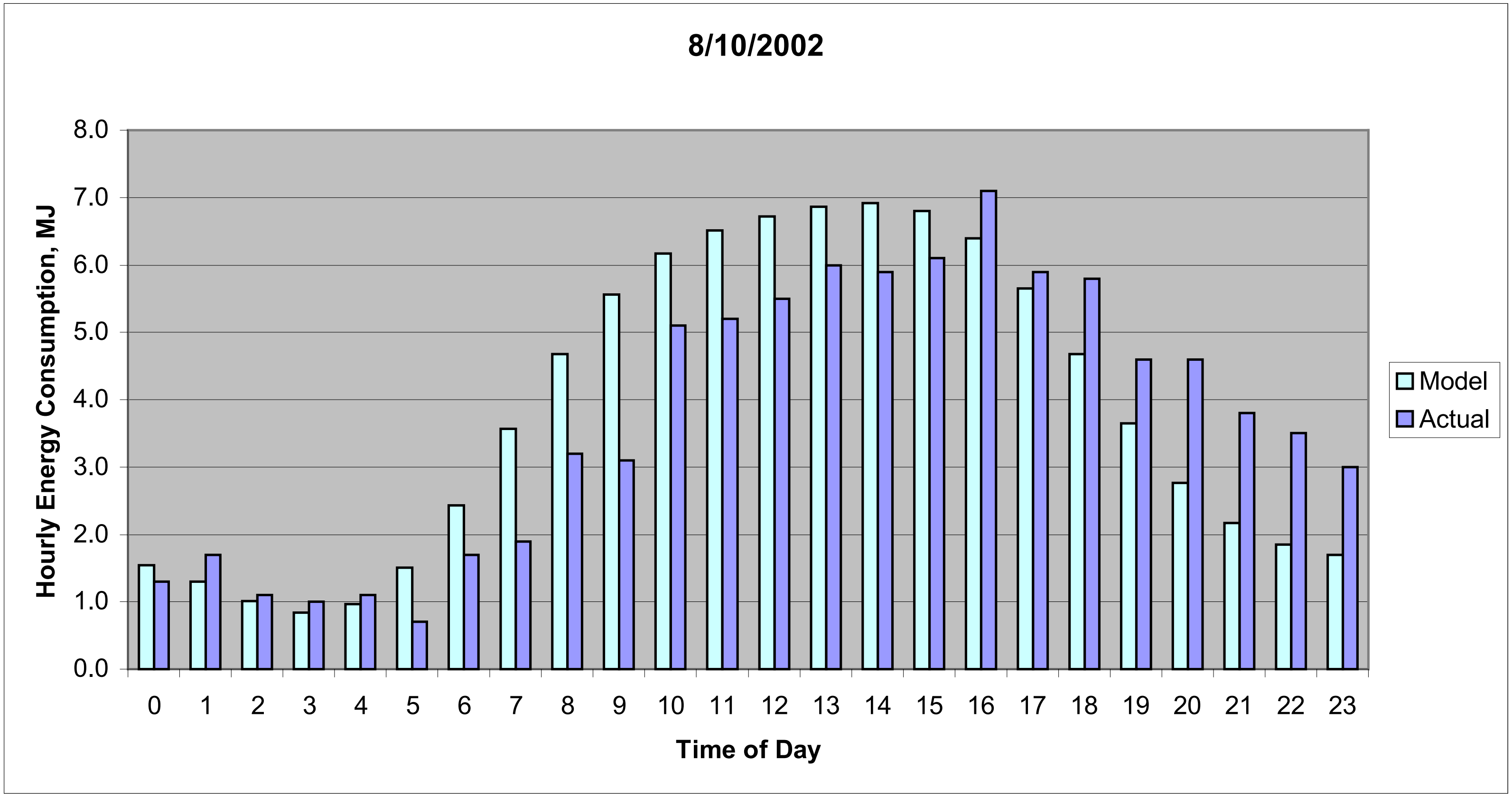


Figure 80. Model predicted versus experimental office building energy data for heating

Table 23. Office Building Cooling Model Comparison Data

Aug. 10, 2002	From Mathcad Model			From Data	
t	q	QM	Model	QA	Actual
0	427.9	1.5	1.5	1.3	1.3
1	360.8	1.3	2.8	1.7	3.0
2	281.0	1.0	3.9	1.1	4.1
3	232.2	0.8	4.7	1.0	5.1
4	267.2	1.0	5.6	1.1	6.2
5	417.7	1.5	7.2	0.7	6.9
6	674.8	2.4	9.6	1.7	8.6
7	990.3	3.6	13.1	1.9	10.5
8	1299.0	4.7	17.8	3.2	13.7
9	1546.0	5.6	23.4	3.1	16.8
10	1712.0	6.2	29.6	5.1	21.9
11	1809.0	6.5	36.1	5.2	27.1
12	1866.0	6.7	42.8	5.5	32.6
13	1905.0	6.9	49.6	6.0	38.6
14	1921.0	6.9	56.6	5.9	44.5
15	1888.0	6.8	63.4	6.1	50.6
16	1775.0	6.4	69.7	7.1	57.7
17	1571.0	5.7	75.4	5.9	63.6
18	1300.0	4.7	80.1	5.8	69.4
19	1013.0	3.6	83.7	4.6	74.0
20	767.8	2.8	86.5	4.6	78.6
21	601.9	2.2	88.7	3.8	82.4
22	514.1	1.9	90.5	3.5	85.9
23	470.7	1.7	92.2	3.0	88.9

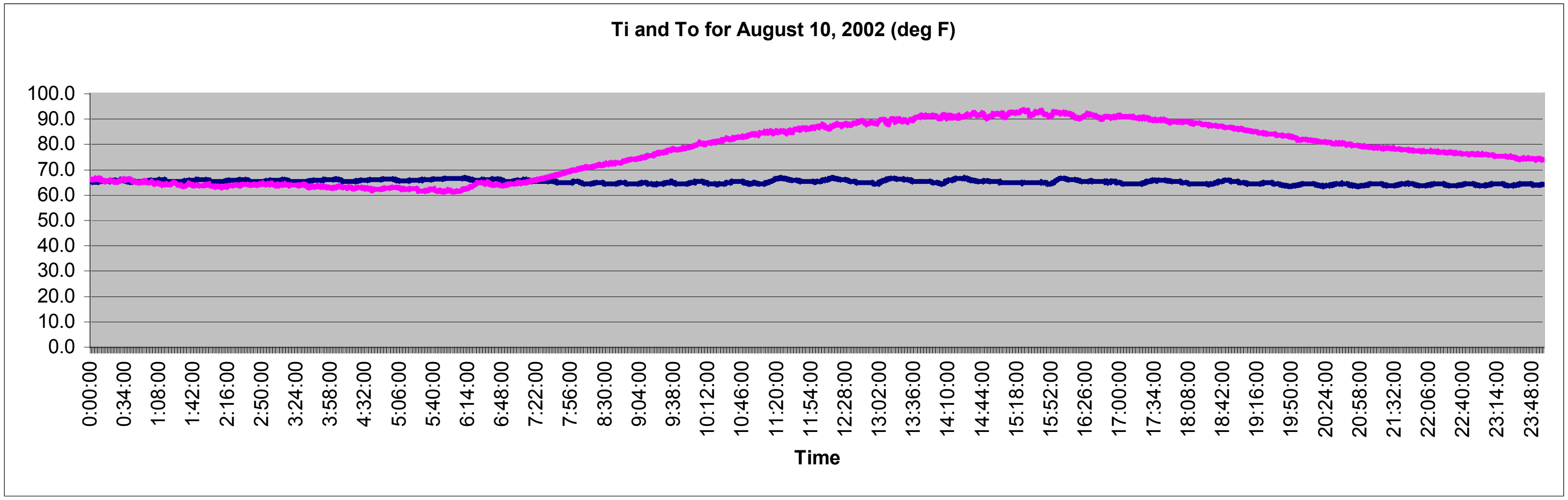


Figure 81. Office building recorded temperatures for cooling model

Test data were also gathered for the warehouse test site in Gary, Indiana. These data are for the case with both sections of the building considered in the analysis and experimental data. Figure 82 shows a comparison of the energy input to the building gathered experimentally and that calculated with the model for heating.

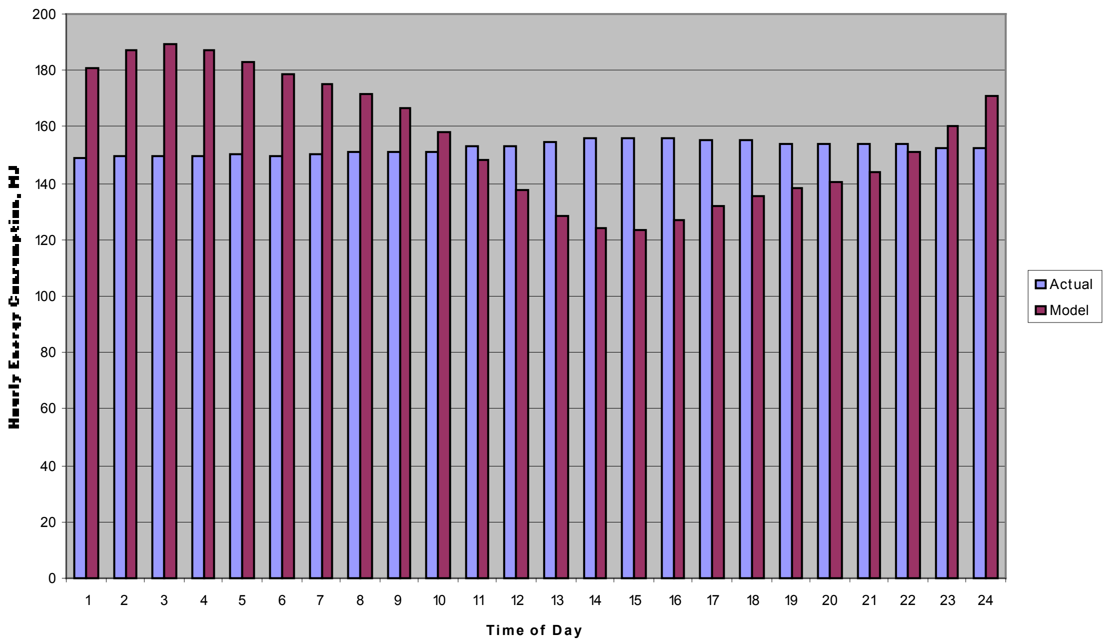


Figure 82. Warehouse heating experimental data and model comparison

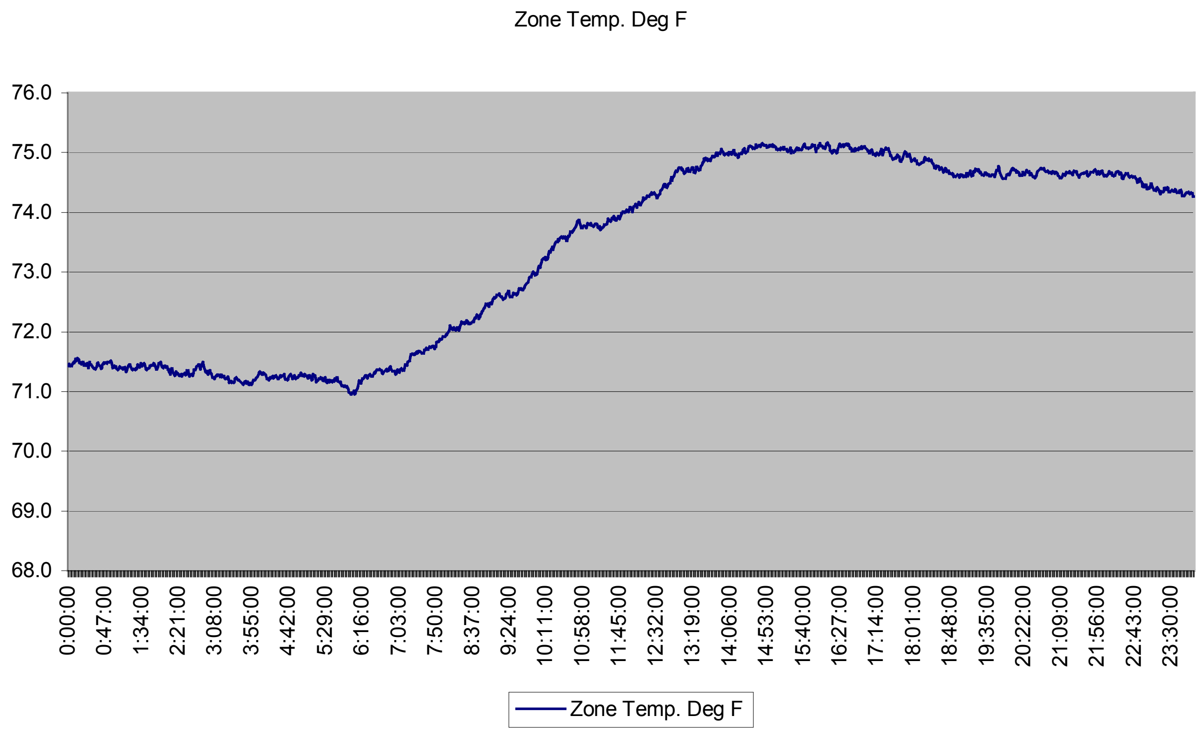


Figure 83. Warehouse heating zone temperatures

Table 24 is the data for Figure 83.

Table 24. Warehouse Heating Comparison Data

Hour	Avg. Amb. Temp °F	Avg. Amb. Temp °C	Energy Into B7 Hourly MJ	Energy Into B7 Total MJ	Model Estimate Avg. Hourly W	Model Estimate Hourly MJ	Model Estimate Total MJ
1	32.6	0.3	149	149	50280	181	181
2	33.2	0.7	149	298	52010	187	368
3	34.2	1.2	150	448	52510	189	557
4	35.4	1.9	150	598	51970	187	744
5	36.3	2.4	150	748	50880	183	928
6	35.9	2.2	150	898	49740	179	1107
7	35.7	2.0	151	1049	48750	176	1282
8	36.3	2.4	151	1200	47710	172	1454
9	38.8	3.8	151	1350	46230	166	1620
10	40.6	4.8	151	1502	44030	159	1779
11	43.2	6.2	153	1655	41180	148	1927
12	44.1	6.7	153	1808	38180	137	2064
13	45.6	7.6	155	1963	35720	129	2193
14	46.7	8.2	156	2119	34380	124	2317
15	46.8	8.2	156	2274	34340	124	2440
16	47.5	8.6	156	2431	35270	127	2567
17	46.4	8.0	156	2586	36560	132	2699
18	45.0	7.2	155	2741	37680	136	2835
19	44.0	6.7	154	2895	38430	138	2973
20	43.1	6.2	154	3050	39070	141	3114
21	42.2	5.7	154	3203	40090	144	3258
22	42.0	5.5	154	3357	41910	151	3409
23	40.9	5.0	153	3510	44550	160	3569
24	40.1	4.5	152	3662	47570	171	3741

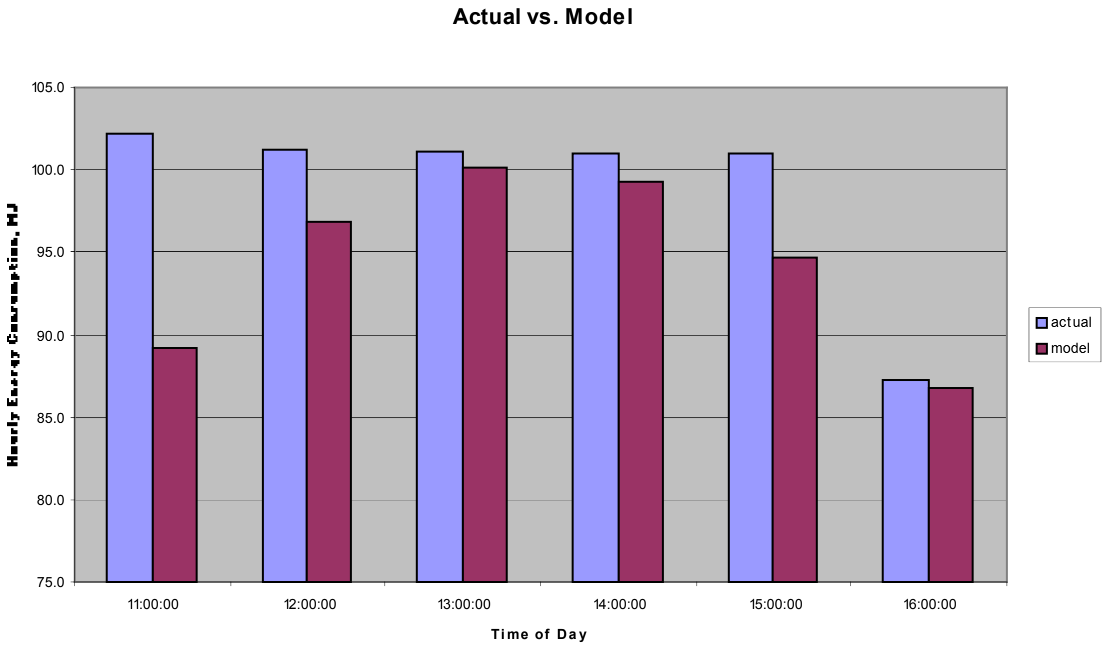


Figure 84. Warehouse cooling model comparison

4.4 Heat Mass Test

When optimizing the performance of a CHP system, as was described in Task 4, it is helpful to have a means of quickly storing and retrieving heat. This allows for more uniform operation of the energy balance of the system and can significantly alter the timing of electric production or purchase.

Figure 85 shows the energy use profile for a typical commercial building with a lot of parking lot lighting. As can be seen from Figure 85, there are periods of time where there is excess or insufficient heat available from the generation of electricity by the CHP system. Rather than reducing the output of the turbine and thereby reducing the excess heat, which generally involves a significant heat rate penalty, the overall efficiency could be increased if the heat could quickly be store and retrieved at other times when it is needed.

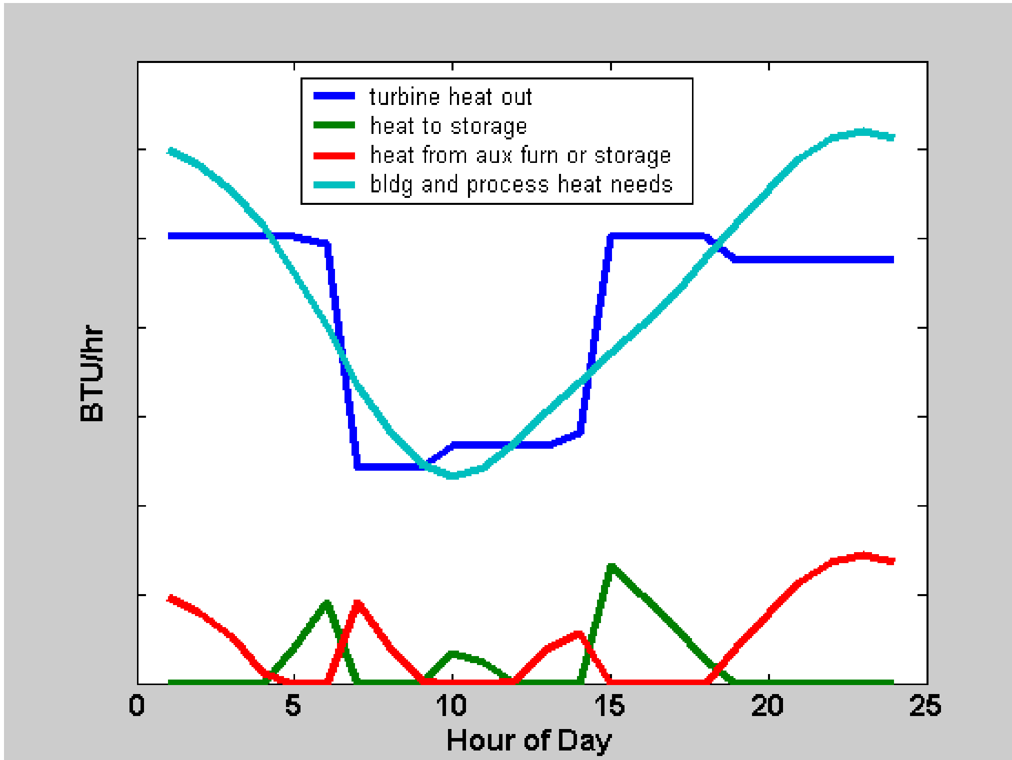


Figure 85. Energy use

A test system was constructed to investigate the feasibility of this type of storage using eutectic salt energy storage material. The phase change for this material occurs at approximately 80°F. A faster and higher-temperature version based on a different heat transfer scheme is now under construction. The results for the test module indicate that this storage may be of assistance in optimizing CHP systems, thereby improving economic viability for a wider range of applications.

The module is shown during final construction in Figure 86. The rate of heat addition is shown in Figure 87. The rate of heat removal is shown in Figure 88.

Figure 86. Heat storage module

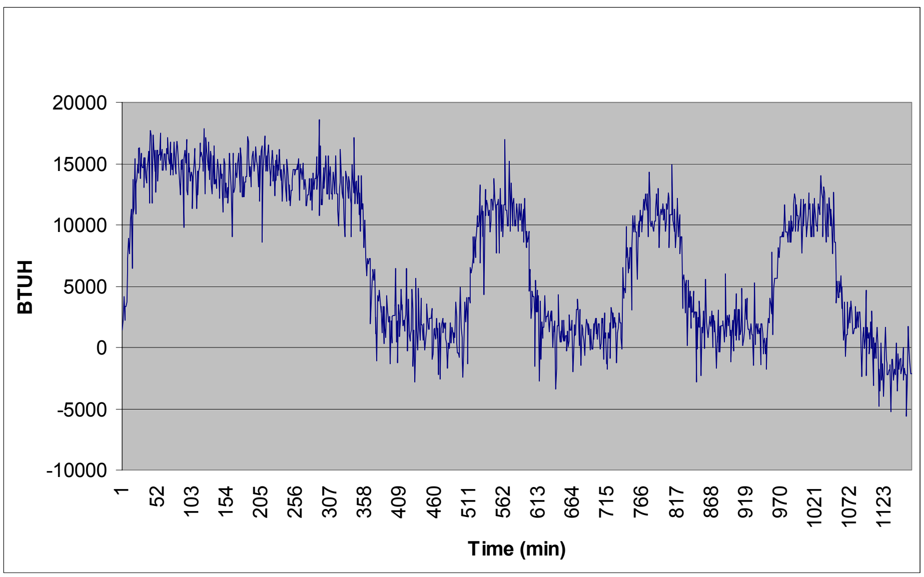


Figure 87. Heat addition to storage module

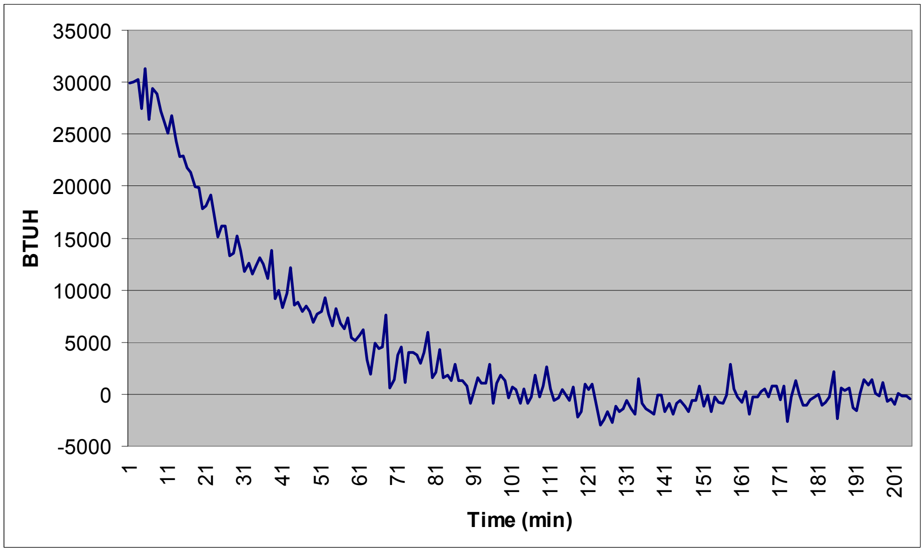


Figure 88. Heat removal from storage module

Additional results can be found in appendices I and J.

4.5 Chesterton Desiccant Test

The desiccant unit shown in Figure 16 was tested with the test matrix shown in Table 25. The purpose of this test sequence was to identify any operating parameters that would be important in the optimized CHP design.

The first response considered is the removal rate of water from the air passing through the desiccant system. An inverse square root transformation was performed on the data after considering the Box-Cox plot shown in Figure 90. Figure 89 shows the half normal plot for this case. As shown in the figure, the only factor selected was “sensible wheel on and off.” The influence of the other factors for the range of experimental values is so outweighed by this factor that no other results were noticed for bulk water removal rate.

The second response is the temperature difference across the regeneration coil. This was considered to understand the influence of the operating parameters on the temperature of the air leaving the regeneration coil before it enters the desiccant wheel for regeneration. Figure 92 shows the half normal plot for this case. The selected factors were “regeneration temperature” and “sensible wheel on and off.” The presence of the sensible wheel provides additional input heat to the entering air stream and influences the coil temperature directly. As shown in Figure 93, the major influence is the regeneration temperature.

The third response is the delta humidity or the change in humidity for the air going through the system. Figure 94 is the half normal plot for this case. As shown in Figure 95, the major influence is the state of the sensible wheel. This is because of the relative magnitude of the contributions made by other factors within the range of observations. Additional information can be found in Appendix K.

The results from these cases show only general trends in the operation of the unit. Additional work needs to be done to extend the range of the parameters so that the sensible wheel effect does not overshadow the other factors. The operating conditions and weather did not allow for this expansion during this part of the project. Additional testing is planned for next year. The test results for the desiccant tests performed in the office building test site in Gary, Indiana, allowed for more control of the parameters and more information regarding the sensitivities of a desiccant system.

Table 25. Chesterton Desiccant Test

Std	Run	Block	Factor 1 A: Regen Fan Speed Hi-Lo	Factor 2 B: Regen Temperature Hi-Lo	Factor 3 C: Sensible Wheel On-Off	Response 1 Water Removal Rate lb H_2O/hr	Response 2 Delta t Coil °F	Response 3 Delta Humidity lb H_2O/lb Air
8	1	Block 1	+1.00	+1.00	+1.00	3.4	67.4	0.00030
7	2	Block 1	-1.00	+1.00	+1.00	3.9	59.7	0.00058
5	3	Block 1	-1.00	-1.00	+1.00	5.6	40.0	0.00084
3	4	Block 1	-1.00	+1.00	-1.00	7.0	96.5	0.00104
4	5	Block 1	+1.00	+1.00	-1.00	14.5	96.5	0.00129
2	6	Block 1	+1.00	-1.00	-1.00	10.7	68.2	0.00095
1	7	Block 1	-1.00	-1.00	-1.00	8.5	67.3	0.00126
6	8	Block 1	+1.00	-1.00	+1.00	4.9	47.2	0.00044

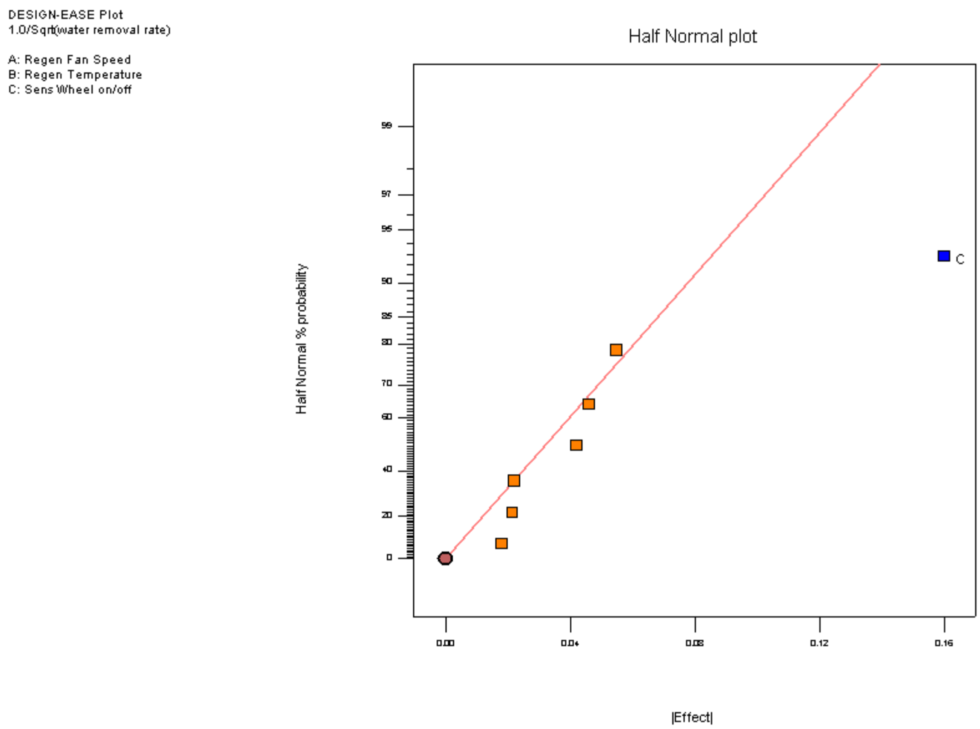


Figure 89. Chesterton desiccant water removal rate (Response 1) half normal plot

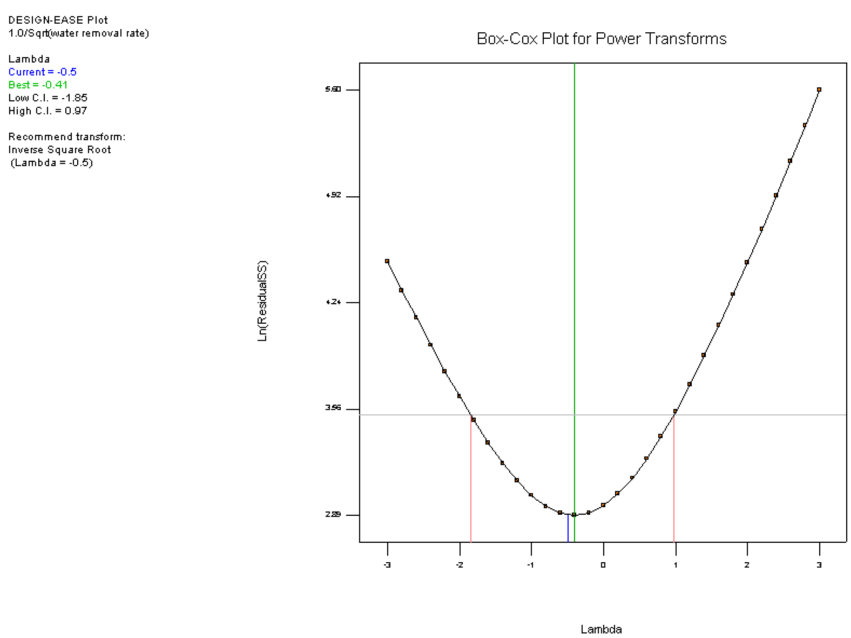


Figure 90. Box-Cox plot for water removal rate

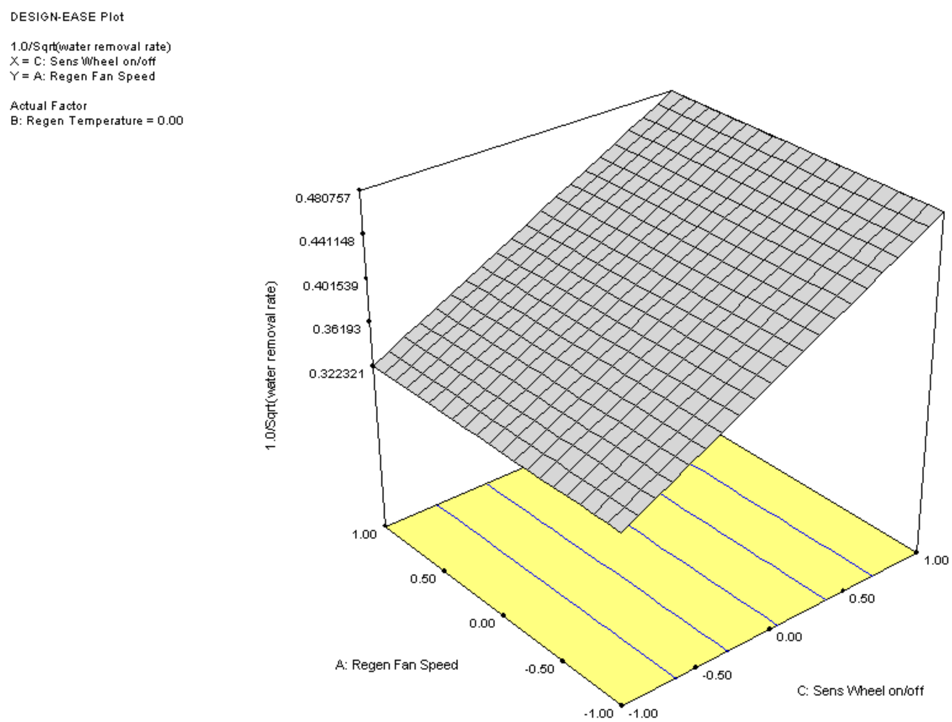


Figure 91. Results for water removal rate

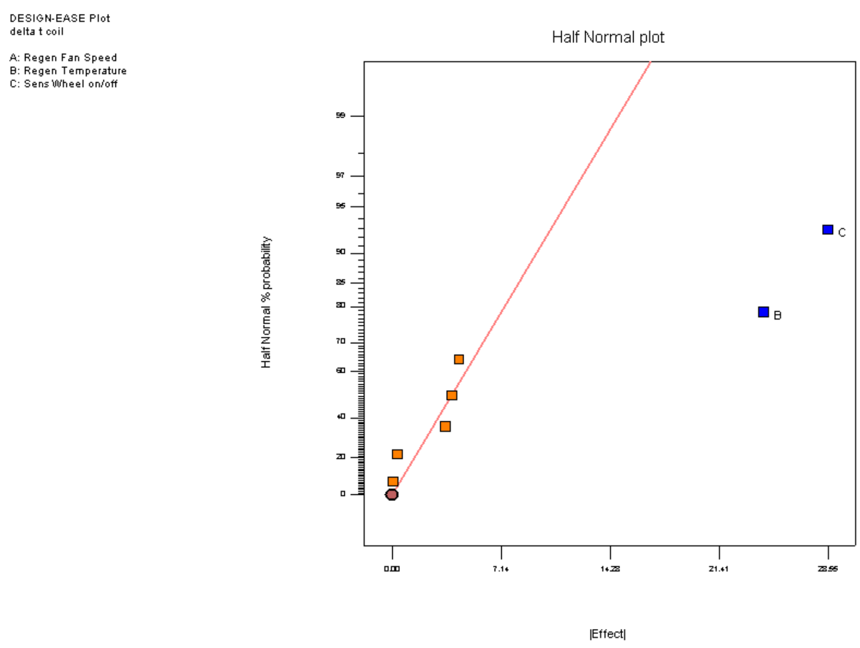


Figure 92. Half normal plot for delta temperature of heater

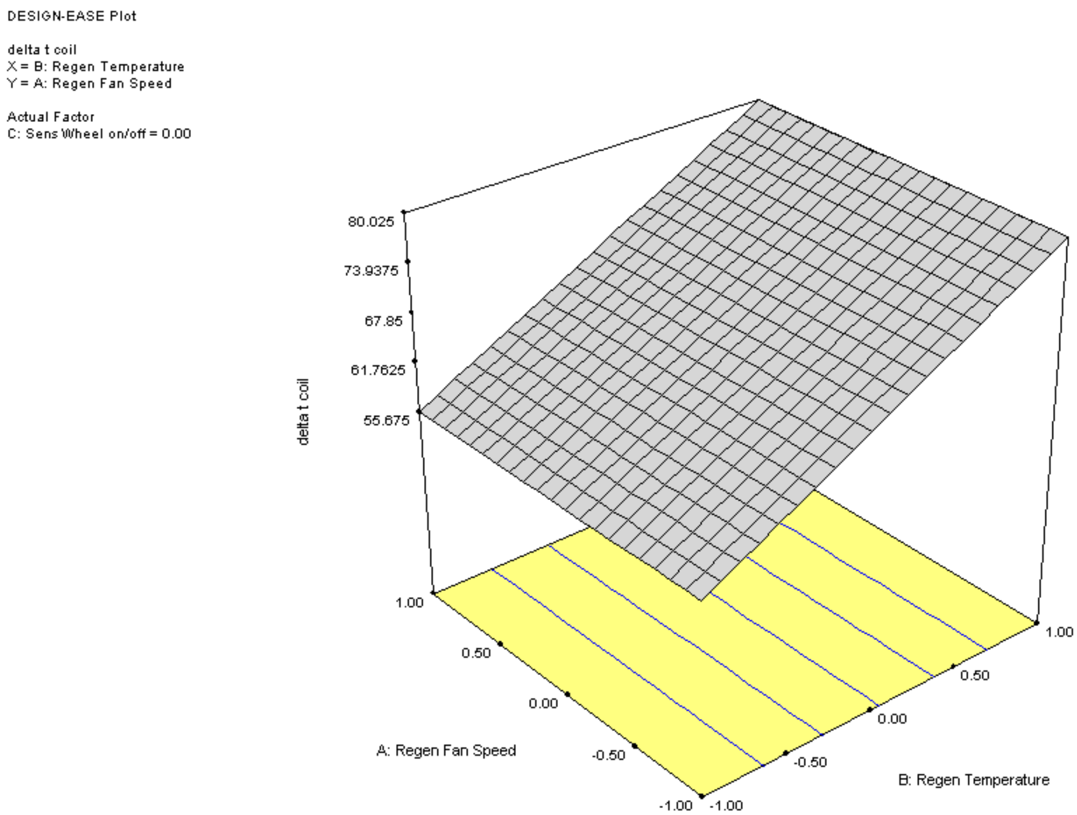


Figure 93. Results for delta temperature of heater

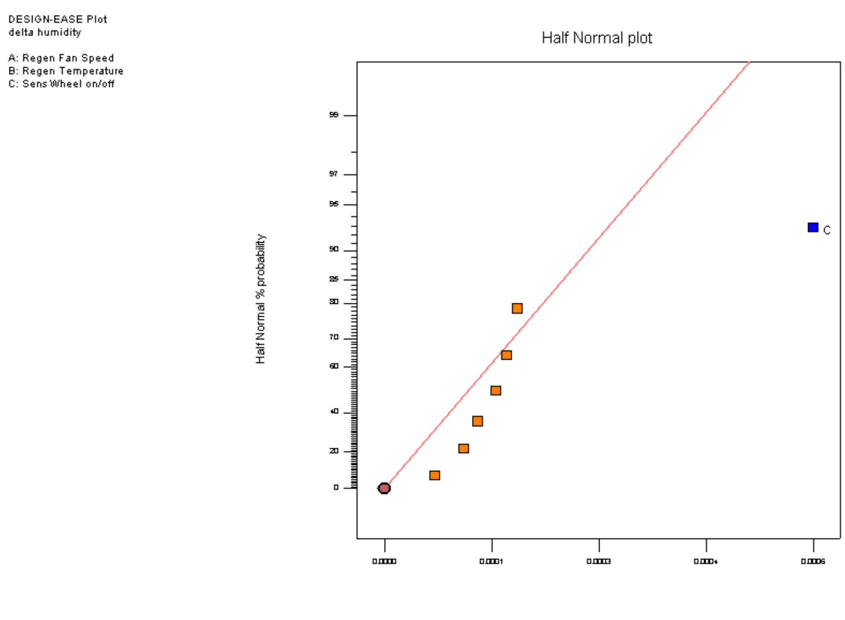


Figure 94. Half normal plot for delta humidity

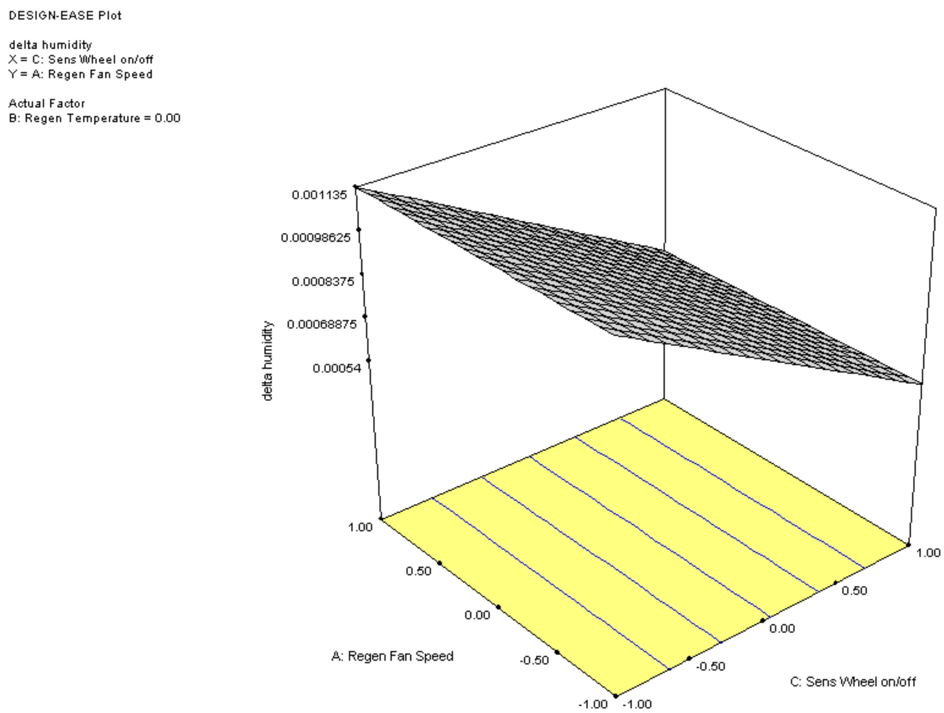


Figure 95. Results for delta humidity

4.6 Breeden Distributed Generation Installation

The Breeden YMCA and Learning Center has been recognized for providing more than just quality recreational programs for Steuben County. The design and capabilities of the building also allow it to serve as a disaster relief center. In November of 2000, the YMCA signed an agreement with the Red Cross to provide the building when needed as a disaster relief center. This raised concerns about the availability of critical building systems during disasters with loss of grid-supplied electrical power. A source of backup power became an obvious need.

At this time, it was decided to pursue the installation of a backup, standby generator. As NiSource considered a request for the donation of a standby generator, it became clear that other DG approaches could deliver better value to the Breeden YMCA.

NET installed a microturbine-based, CHP system at the Breeden YMCA. A multiyear, phased approach will be followed to complete this installation. The first phase will include electrical power generation equipment to provide a portion of the building's electrical demand and heat recovery equipment to supplement building space heating and swimming pool heating requirements. Phase 2 will include adding dehumidification capability to the system to further reduce the load on building HVAC systems. Phase 3 will include the integration of a proprietary building energy management control system to optimize the entire building energy use profile.

The initial installation consists of two microturbine generator sets, each with a rated output of 60 kW operating in parallel with the local electric delivery system. The microturbine system is sized considerably below the facility's peak demand. The connection prevents any electrical power from being back fed into the local utility's system. Electrical circuits within the Breeden facility were modified to allow for the segmentation and maintenance of critical loads during times of grid outage.

The energy contained in the hot turbine exhaust gas is recovered for use in the YMCA by a recovery heat exchanger. A portion of the building hot water loop flow will be channeled though this heat exchanger to capture heat from the exhaust gas flow. This added heat will reduce the operating time of the existing boilers. This reduces the cost of building space heating and swimming pool heating and extends the life of the boilers.

The Breeden YMCA facility derives the following benefits from this project:

- Flexibility in evolving energy markets
- Improved reliability of electrical supply
- Publicity from employing leading-edge technologies.

4.6.1 Interconnection Issues

Although it was agreed that the installation would meet the IEEE 1547 standard for interconnection, the standard was still at the Draft 10 stage at the time of this report. Discussions centered on the liability of the system owner and the need for the owner to agree to a standard that is still subject to change (and has the potential of imposing additional costs to the project). Also during this time, the standby service rider, Rider SR, Rider to Schedule "LP-3," was introduced with the proposed DG contract and rules of interconnection.

Technical issues during this time centered on the location of the visible disconnect switch, the automatic transfer switch timing and operation, and the installation of reverse flow metering equipment. Net metering, the sale of electricity to the local utility, and reverse flow are not allowed at this location. The local utility required metering devices to detect and measure reverse power flow. The utility modified the billing meter to output forward pulses at the rate of 72 W per pulse and installed a maintained contact for reverse power. These outputs from the local utility meter become inputs to the turbine control system and either increase or decrease power output. The current transformers and potential transformers for the reverse flow meters are installed between the generators and the main disconnect panel. The reverse flow meter is placed on the outside of the building so it is always accessible to local utility personnel. A telephone communications line was required for the exclusive use of the local utility for revenue and reverse power flow monitoring and control.

Traditional generation usually involved interfacing protective relaying to the generator control system. In these cases, wiring integrity and relay settings would have to be tested for each and every generation system. In this installation, the prime mover, inverter control, and protective relaying are in one integral package. IEEE 1547 Section 5.1 permits the design testing for DG systems to be performed on a representative sample, or "type tested." UL had already type tested and certified this package, which reduced the scope of required field testing to IEEE Section 5.4 commissioning testing.

On August 22, 2002, the YMCA hosted a dedication ceremony and press conference to describe the installation and announce the national energy and environmental benefits of the project. The microturbines were demonstrated in standalone mode. The local utility was informed of this operation and had no objections. All major systems were complete, and final control settings were on hold pending the contract signing, which occurred on August 29, 2002.

The control system is being used as a data acquisition system to log system information such as temperature, pressure, flow, power and status. The "front end" to the system is a program that will link the local utility to the YMCA system for operational verification and safety. The local utility will have access, via a standard Web browser, to specific data from the YMCA data acquisition system. This data will allow the local utility to determine the operational status of the DG resource, including output power level, voltages, currents, and frequencies. In addition, the position of the automatic transfer switch will be available to the local utility.

4.6.2 Breeden YMCA Loss of Phase Isolation Test

The purpose of this testing was to demonstrate the isolation capabilities and reverse power protection of the Breeden facility.

The control scheme and sequence of operation is described in Figure 96.

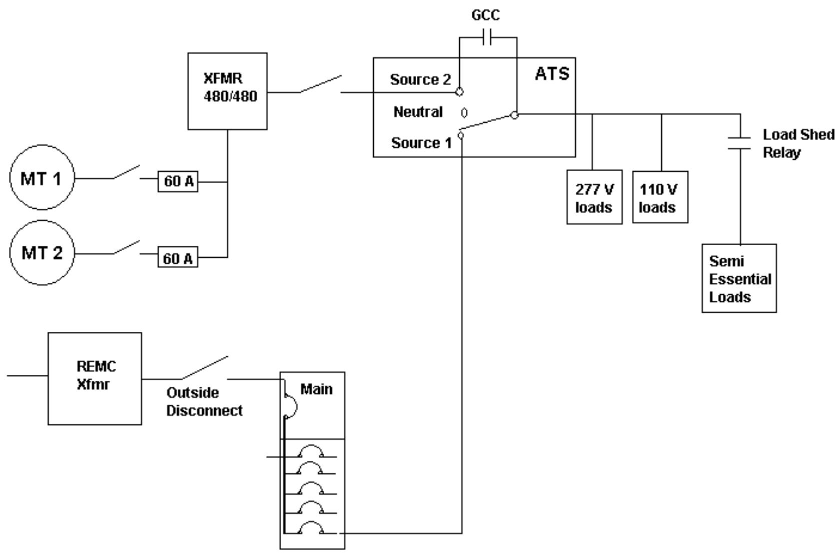


Figure 96. Transfer scheme

A discussion concerning the contract language revealed that safety was the intent of the "1-second reverse power trip" of section 7 of Exhibit A of the interconnect agreement between the YMCA and the local utility. It was explained that there were two control schemes for reverse power protection: one for safety, with trip settings less than 0.1 second, and a second pulse-averaging method for commercial considerations. After the schemes were described, the consultant said that his concern was safety and the default setting of 0.095 seconds would suffice, but he wanted to see a live test. The local utility engineer suggested that the averaging of the commercial pulses be set at 10 seconds, and operating experience would determine the kilowatt input offset that would be programmed into the control logic.

The field test consisted of operating the turbines in the "normal" grid-connect mode, individually interrupting each phase at the 12 kV input to the local pad mount distribution transformer to simulate the loss of a distribution phase and verify that the microturbines would shut down in less than 1 second. Large motors in the building were shut down prior to the test to minimize damage caused by single phasing three-phase motors. The test was performed at 10:30 p.m. to avoid interfering with the normal operation of the YMCA. The microturbines shut down and did not re-energize until all three phases were restored. The fast under voltage trip (0.095 seconds) operated in all three tests.

- Grid outage with the transfer of power to the turbines in standby mode was demonstrated.
- Inspection of the electrical system by the engineer and superintendent of the local utility was completed. All systems performed per specifications and were accepted by the local utility.
- The test of the reverse flow meter was completed.
- All controls were tested during the month for proper connections and operation.
- The system was running grid-connected under the supervision of NET personnel and the verbal authorization of the local utility to test and finalize settings for the installation when operating in parallel with the grid. The final testing, per the requirement of the contract, was scheduled.

4.6.3 YMCA Transfer Scheme

In the "normal," grid-connected situation, all switches and contactors are closed, and the automatic transfer switch is in the Source 1 position.

Upon loss of grid power, programmable timer TDNE (time delay normal to emergency, set for 10 seconds) starts in the automatic transfer switch, the grid connect contactor and the load shed relay open, and the microturbines shut down. The automatic transfer switch signals the microturbines to go to standalone connect if the grid connect contactor has dropped out.

If grid power returns before the TDNE times out, the turbines will return to grid-connect mode, the grid connect contactor will re-energize, and the turbines will restart after a cool-down period. (During this cool-down period, a user connection fault will appear on the microturbine display.)

If the grid does not return after the TDNE times out, the turbines will restart in standalone mode. Once they reach loading speed, the automatic transfer switch senses that the Source 2 voltage is present and switches to the neutral position for 4 seconds and then continues on to the Source 2 connected position. The turbines will now load up and carry critical loads.

If both turbines load up, the load shed relay will energize, and the semi-critical loads will also be serviced. When the grid returns, programmable timer TDEN (time delay emergency to normal, set for 60 seconds) starts counting down. After the grid has returned and is stable for this time period, the transfer switch will move to the neutral position and signal the turbines to shut down. The turbine output contactors internal to the microturbines open immediately. After 4 seconds in the neutral position, the automatic transfer switch will switch back to the Source 1 position, and the turbines will be signaled to go to the grid-connect mode. The grid connect contactor will close when it has received a signal that the automatic transfer switch is not in the Source 2 position and the turbines are not in standalone mode. The turbines will then recharge their batteries for 15 to 20 minutes before resuming grid-connect operation. (During that time, the turbines will indicate a user connection or other fault.)

Figure 97 shows the small extension on the corner of the NiSource turbine building that houses the CHP project.

Figure 97. Turbine building

The electrical output sizing of the microturbine generator installation will allow the generators to run at or near their most efficient operating point. Figure 98 shows the turbines and heat exchanger.

Figure 98. Turbines and heat exchanger

A portion of the facility hot water loop flow will be routed through the heat exchange module and returned to the building loop upstream of the boilers. This liquid serves as the heat exchange medium to transmit the energy from the turbine exhaust gas into the facility where it will be used. The water is returned to the system upstream of the boilers at a high temperature, reducing boiler run time required to maintain the temperature of the circulation loop.

The heat exchanger module is equipped with a bypass damper capable of directing the hot gases away from the heat exchanger and directly to the atmosphere. This damper, with an associated control loop, is used to control the outlet temperature of the liquid absorbing the heat energy. The benefit of this approach is that the operation of the cogeneration system is completely transparent to the rest of the building management control systems. The Breeden YMCA facility heat loads—such as the swimming pool, the therapy pool, and general space heating—are served by a circulated hot water system.

This existing building hot water system is designed with three modulating gas-fired boilers to provide the required heat energy input. The boilers have a rated output of 1.02 million btu/hr and a design efficiency of 85%. The total flow in the facility circulated hot water loop is 350 gpm, and the boiler controls are designed to maintain the water in this loop at a constant temperature. It is anticipated that these boilers will become standby boilers because of the CHP system. Figure 99 shows the existing central heating system.

Figure 99. Existing heating system

A copy of a local press release for the project is contained in Appendix H.

5 Conclusions: Second Year

A major goal of this work was to develop concepts that will advance the penetration of IES technology into the marketplace and increase its use as a resource for meeting future national energy needs. In Task 4, system design issues were considered to increase the overall efficiency of the system. This is important to make the technology competitive with other energy options such as conventional grid power. Optimization and testing were performed on IES components and building integration concepts to increase efficiency, reliability, and applicability. Issues relating to how an IES might be connected to the grid for a particular location and purpose were considered.

Task 5 considered how an IES might be connected to the existing electric grid and issues associated with that interconnection. This effort considered grid operation and how it influences the operation of a CHP IES. The interconnection requirements of utilities in the NiSource territory were considered. These were then contrasted and related to current CHP technologies. Details relating to actual interconnection requirements and how they influence installation timing and costs were considered.

Task 6 considered the performance of four CHP systems. The first was a small office building in Gary, Indiana. The second was a warehouse in Gary, Indiana. The third was an operating commercial drug store in Chesterton, Indiana, and the fourth was a YMCA in Breeden, Indiana. Initially, the control influences on the IES as they relate to the grid interface were considered. Detailed, statistically based and other testing was performed on the systems in Gary, Indiana. These tests provided information and recommendations for the combination and operation of CHP components, controls, and operating techniques. Components considered included microturbines, battery energy storage devices, desiccant dehumidification, absorption cooling, building heating, ERVs, thermal energy storage devices, power quality devices, and control and data acquisition systems. A building model was developed and used to extend the design and operating recommendations. Aspects of the interaction of the system under varying conditions were considered.

The controls for the IES responded to all the situations that arose from the interaction with the grid. Several problems with turbine reliability related to interaction with the grid were noted at the Chesterton, Indiana, site. Some of these problems caused extended outages of the system. Current indications are that turbine component reliability issues have been reduced with design and operating changes made by the manufacturer of the turbine. This is, however, a concern that could influence future microturbine CHP system viability.

The systems performed as designed and reliably for a variety of conditions. Issues of power quality and grid interaction did not seem significant for the current installation. As the penetration of DG systems increases, these aspects will become more noticeable. Essentially, there should be no concern with low levels of penetration on a particular distribution feeder. It was found that 120 kW of microturbine generation had no influence on the operation of the distribution feeder in Gary. As the penetration level increases, inductive transients first surface as a concern. This will restrict those applications in which there is significant motor starting, including such devices as refrigeration and process handling equipment.

The major electrical interaction between the grid and the DG system was determined to be the effect of transients originating on the grid because of switching or other circumstances on the turbine. Even with two industrial-quality surge suppression devices attached to the system, there were circumstances under which the turbine tripped because of transients from the grid. This did not occur frequently, but because of the use of IES as a potential backup source during storms, it requires special attention. One recommendation is to always include surge suppression at the point of coupling in addition to what may be supplied by the vendor for the particular DG device. It is estimated that such devices have reduced component failures and associated outages by at least 25% at the Chesterton test site.

From the two test sites in Gary and the Chesterton test site, it was possible to test a variety of CHP combinations and functions. The influences of various systems on the efficiency were considered. Aspects of the interactions among CHP components were investigated, and recommendations for future designs were made. The report contains recommendations regarding the optimal components and sequence of operation for specific conditions. The reliability and power quality aspects of each system were considered.

The building models developed and tested for the facilities were tested against experimental data. Refinements were made to the models accordingly. A dynamic model for the control of CHP building applications was developed. This model employs neural networks and fuzzy logic in a predictive control scheme. The goal of the model is to minimize the cost of the operation of the system by dynamically controlling the energy within the building.

The YMCA project is operational and producing information that can be used for other demonstrations of CHP technology.

Appendix A. Case 3 Desiccant Dehumidifier Performance Data

Table A-1. Case 3 Desiccant Dehumidifier Performance Data

Date	Time	Process In °F	Process In RH%	Process Out °F	Process Out RH%	Regen In °F	Regen In RH%	Regen Out °F	Regen Out RH%
10/30/2002	13:55:00	69.9	30.0	106.3	4.5	49.1	58.1	105.2	7.2
10/30/2002	13:56:00	70.6	30.0	105.1	7.1	49.4	59.3	102.8	7.2
10/30/2002	13:57:00	71.5	30.0	102.9	10.5	50.0	57.4	99.7	7.2
10/30/2002	13:58:00	72.3	29.9	100.8	11.6	50.3	57.2	96.7	7.2
10/30/2002	13:59:00	73.2	29.6	98.8	13.3	51.0	57.2	94.6	7.2
10/30/2002	14:00:00	74.1	29.4	96.9	14.9	51.7	54.5	92.6	7.2
10/30/2002	14:01:00	74.9	29.2	95.3	16.4	52.4	54.8	90.7	7.2
10/30/2002	14:02:00	76.2	27.7	98.1	10.4	52.7	54.4	97.5	7.2
10/30/2002	14:03:00	78.5	24.6	111.2	6.3	51.4	58.0	108.6	7.2
10/30/2002	14:04:00	79.0	24.0	116.2	4.9	50.3	61.9	112.7	7.2
10/30/2002	14:05:00	78.0	23.2	116.7	4.2	49.7	61.2	114.5	7.2
10/30/2002	14:06:00	74.8	26.0	114.2	3.5	49.5	61.2	113.7	7.2
10/30/2002	14:07:00	72.8	28.3	112.2	4.1	49.4	60.7	114.3	7.2
10/30/2002	14:08:00	72.5	26.6	112.9	4.1	49.1	61.7	114.9	7.2
10/30/2002	14:09:00	72.9	25.5	113.3	4.1	49.1	60.8	115.9	7.2
10/30/2002	14:10:00	73.1	24.9	113.5	4.1	49.1	59.8	116.3	7.2
10/30/2002	14:11:00	73.2	24.6	113.3	4.0	49.4	59.5	116.7	7.2
10/30/2002	14:12:00	73.3	24.2	113.3	4.0	49.2	59.9	116.8	7.2
10/30/2002	14:13:00	73.5	23.9	113.1	4.0	48.7	62.1	116.9	7.2
10/30/2002	14:14:00	73.3	23.9	113.0	4.0	48.5	61.8	117.0	7.2
10/30/2002	14:15:00	73.2	23.8	112.8	4.0	48.5	61.5	117.0	7.2
10/30/2002	14:16:00	72.9	23.8	112.7	3.9	48.3	62.9	116.8	7.2
10/30/2002	14:17:00	73.2	24.2	111.8	3.9	48.4	62.3	115.2	7.2
10/30/2002	14:18:00	74.1	24.3	110.1	6.9	49.0	62.6	111.8	7.2
10/30/2002	14:19:00	75.0	24.3	107.8	8.6	49.8	58.5	109.3	7.2
10/30/2002	14:20:00	75.8	24.1	105.2	9.7	50.5	56.9	106.3	7.2
10/30/2002	14:21:00	76.8	23.1	106.8	5.2	50.9	56.1	110.0	7.2
10/30/2002	14:22:00	77.1	22.3	110.9	4.8	50.4	57.7	111.3	7.2
10/30/2002	14:23:00	76.8	22.5	110.4	4.7	49.7	59.8	111.1	7.2
10/30/2002	14:24:00	76.0	22.8	109.5	4.7	48.9	61.3	110.3	7.2
10/30/2002	14:25:00	75.3	23.0	108.7	4.7	48.5	62.1	109.9	7.2

10/30/2002	14:26:00	74.8	23.1	108.2	4.7	48.5	62.5	109.7	7.2
10/30/2002	14:27:00	74.4	23.1	107.7	4.8	48.6	61.6	109.7	7.2
10/30/2002	14:28:00	74.0	23.1	107.5	4.7	48.7	61.6	109.7	7.2
10/30/2002	14:29:00	73.7	23.2	107.3	4.8	49.0	62.0	109.8	7.2
10/30/2002	14:30:00	73.5	23.3	107.2	4.7	49.1	61.5	109.8	7.2
10/30/2002	14:31:00	73.6	23.6	106.6	4.7	49.1	62.4	108.8	7.2
10/30/2002	14:32:00	74.4	23.5	105.0	8.8	49.7	63.8	106.8	7.2
10/30/2002	14:33:00	75.2	23.4	102.9	10.1	50.5	59.2	104.3	7.2
10/30/2002	14:34:00	76.2	23.0	100.9	11.2	51.3	57.0	102.1	7.2
10/30/2002	14:35:00	76.9	21.0	98.5	12.2	52.3	57.1	99.7	7.2
10/30/2002	14:36:00	76.8	20.8	95.0	12.4	53.5	49.3	97.8	7.2
10/30/2002	14:37:00	75.7	23.5	98.2	7.0	53.8	51.8	103.4	7.2
10/30/2002	14:38:00	74.7	24.0	105.2	5.6	52.1	57.5	107.8	7.2
10/30/2002	14:39:00	74.2	23.6	107.2	5.1	50.6	60.6	109.5	7.2
10/30/2002	14:40:00	74.0	23.2	107.6	4.9	49.8	62.2	109.8	7.1
10/30/2002	14:41:00	73.9	23.1	107.3	4.8	49.4	62.0	109.9	7.1
10/30/2002	14:42:00	73.6	22.9	107.0	4.8	49.0	60.8	109.6	7.1
10/30/2002	14:43:00	73.5	22.7	106.7	4.8	48.4	63.2	109.4	7.1
10/30/2002	14:44:00	73.5	22.6	106.6	4.8	48.2	63.1	109.4	7.1
10/30/2002	14:45:00	73.5	22.5	106.4	4.8	47.9	64.0	109.5	7.2
10/30/2002	14:46:00	73.4	22.3	106.3	4.8	48.0	64.0	109.7	7.2
10/30/2002	14:47:00	73.0	23.2	105.9	4.5	48.5	61.0	109.0	7.1
10/30/2002	14:48:00	72.3	24.6	103.4	8.9	49.2	62.0	107.4	7.1
10/30/2002	14:49:00	71.7	25.6	97.9	10.6	50.1	60.4	105.5	7.1
10/30/2002	14:50:00	71.2	27.0	93.7	10.8	51.2	56.9	103.3	7.1
10/30/2002	14:51:00	70.7	27.3	99.4	6.3	51.0	57.6	108.3	7.1
10/30/2002	14:52:00	70.4	25.9	106.1	4.9	50.0	61.3	111.7	7.2
10/30/2002	14:53:00	70.7	24.6	108.5	4.5	49.2	63.8	114.3	7.1
10/30/2002	14:54:00	70.8	23.8	109.7	4.3	48.7	63.4	115.7	7.1
10/30/2002	14:55:00	71.3	23.2	109.9	4.2	48.5	64.9	116.6	7.1
10/30/2002	14:56:00	71.3	22.7	110.0	4.1	48.5	60.4	116.9	7.1
10/30/2002	14:57:00	71.4	22.4	110.0	4.0	48.2	61.4	117.1	7.1
10/30/2002	14:58:00	71.6	22.1	109.9	4.0	47.6	64.0	117.3	7.1
10/30/2002	14:59:00	71.6	21.9	109.8	4.0	47.5	64.9	117.7	7.1

10/30/2002	15:00:00	71.6	21.7	109.8	4.0	47.6	64.3	117.8	7.1
10/30/2002	15:01:00	71.6	22.0	109.4	3.8	47.4	66.1	116.9	7.1
10/30/2002	15:02:00	71.6	24.0	107.9	6.5	47.8	65.0	114.7	7.1
10/30/2002	15:03:00	71.3	25.3	104.1	9.0	48.5	63.5	112.0	7.2
10/30/2002	15:04:00	71.0	26.1	102.4	5.8	49.1	61.6	112.4	7.2
10/30/2002	15:05:00	70.3	25.6	105.4	4.5	48.7	62.2	112.4	7.2
10/30/2002	15:06:00	70.0	24.8	105.2	4.6	48.6	64.0	111.4	7.2
10/30/2002	15:07:00	69.9	24.4	104.4	4.7	48.5	65.4	110.2	7.2
10/30/2002	15:08:00	69.7	24.3	103.8	4.8	48.5	64.5	109.7	7.1
10/30/2002	15:09:00	69.7	24.2	103.4	4.9	48.6	67.1	109.3	7.1
10/30/2002	15:10:00	69.7	24.2	103.2	4.9	49.1	61.8	109.3	7.1
10/30/2002	15:11:00	69.7	23.9	103.3	4.8	49.0	61.3	108.9	7.1
10/30/2002	15:12:00	69.7	23.7	103.3	4.8	48.7	61.3	108.8	7.1
10/30/2002	15:13:00	69.7	23.6	103.3	4.7	48.2	63.3	108.9	7.1
10/30/2002	15:14:00	69.7	23.5	103.3	4.6	47.6	64.8	109.1	7.1
10/30/2002	15:15:00	69.8	23.6	102.9	4.6	47.5	64.8	108.0	7.2
10/30/2002	15:16:00	70.5	23.6	101.6	6.6	48.0	64.2	107.1	7.2
10/30/2002	15:17:00	71.8	22.0	103.5	5.0	48.1	63.1	108.5	7.2
10/30/2002	15:18:00	72.4	21.6	104.7	4.8	47.9	65.6	109.6	7.2
10/30/2002	15:19:00	72.2	21.7	104.9	4.7	48.0	62.6	110.1	7.2
10/30/2002	15:20:00	71.9	21.9	104.7	4.6	47.8	62.7	110.0	7.2
10/30/2002	15:21:00	71.5	21.9	104.4	4.6	47.7	64.7	110.0	7.2
10/30/2002	15:22:00	71.3	21.9	104.1	4.7	48.0	66.5	110.2	7.2
10/30/2002	15:23:00	71.0	22.0	103.8	4.7	47.7	64.3	110.1	7.2
10/30/2002	15:24:00	70.8	22.0	103.6	4.7	47.6	64.9	109.9	7.2
10/30/2002	15:25:00	70.8	22.0	103.4	4.7	48.0	64.5	110.0	7.2
10/30/2002	15:26:00	70.8	22.0	103.3	4.7	48.0	65.4	110.0	7.2
10/30/2002	15:27:00	70.7	22.2	102.9	4.4	48.2	67.1	109.1	7.2
10/30/2002	15:28:00	71.2	22.2	101.4	7.8	48.7	65.1	106.8	7.2
10/30/2002	15:29:00	71.8	22.3	98.9	10.3	49.6	63.2	104.3	7.2
10/30/2002	15:30:00	72.5	22.5	96.8	11.1	50.4	60.4	101.8	7.2
10/30/2002	15:31:00	73.3	22.5	95.0	12.2	51.3	59.7	98.9	7.2
10/30/2002	15:32:00	74.2	22.5	93.5	13.1	52.2	58.7	95.8	7.2
10/30/2002	15:33:00	75.0	22.5	92.3	13.7	53.0	54.2	93.6	7.2

10/30/2002	15:34:00	75.7	22.4	91.4	14.5	53.6	52.9	92.2	7.2
10/30/2002	15:35:00	76.4	22.3	90.5	15.7	54.2	52.7	90.7	7.2
10/30/2002	15:36:00	77.0	22.3	89.6	16.5	55.0	52.4	89.3	7.2
10/30/2002	15:37:00	77.5	22.4	88.5	16.9	55.6	51.4	87.7	7.2
10/30/2002	15:38:00	77.7	22.5	87.3	17.4	56.0	48.1	86.8	7.2
10/30/2002	15:39:00	77.8	22.4	89.7	12.1	55.8	50.0	94.3	7.2
10/30/2002	15:40:00	77.2	22.3	104.0	6.7	53.1	57.2	108.8	7.2
10/30/2002	15:41:00	76.5	21.7	110.3	4.9	50.8	62.9	113.2	7.2
10/30/2002	15:42:00	75.9	21.3	111.7	4.4	49.6	63.7	115.4	7.2
10/30/2002	15:43:00	75.5	21.0	111.9	4.3	49.0	61.9	116.2	7.2
10/30/2002	15:44:00	75.2	20.9	111.7	4.2	48.2	63.8	116.5	7.2
10/30/2002	15:45:00	74.9	20.6	111.4	4.2	47.5	64.9	116.8	7.2
10/30/2002	15:46:00	74.6	20.4	111.2	4.1	47.3	65.2	117.0	7.2
10/30/2002	15:47:00	74.4	20.3	111.0	4.1	47.4	63.5	117.3	7.2
10/30/2002	15:48:00	74.1	20.3	110.9	4.0	47.5	63.8	117.6	7.2
10/30/2002	15:49:00	73.8	20.5	110.7	3.9	47.7	65.0	117.7	7.2
10/30/2002	15:50:00	73.2	22.6	110.0	4.2	48.2	61.5	116.3	7.2
10/30/2002	15:51:00	72.3	24.4	107.0	8.2	48.8	60.9	113.8	7.2
10/30/2002	15:52:00	71.6	25.5	101.9	8.4	49.6	60.4	110.5	7.2
10/30/2002	15:53:00	70.3	26.2	103.9	4.6	49.6	61.9	114.3	7.2
10/30/2002	15:54:00	69.3	25.3	107.1	4.3	48.8	65.2	115.8	7.2
10/30/2002	15:55:00	68.9	24.8	107.6	4.2	48.2	65.8	116.7	7.2
10/30/2002	15:56:00	68.6	24.9	107.7	4.1	47.9	66.2	116.7	7.2
10/30/2002	15:57:00	69.0	23.9	107.9	4.2	47.9	66.2	116.8	7.1
10/30/2002	15:58:00	69.4	23.2	108.1	4.2	47.6	66.3	116.8	7.2
10/30/2002	15:59:00	69.7	22.6	108.2	4.1	47.2	67.1	116.9	7.2
10/30/2002	16:00:00	70.1	22.2	108.2	4.1	46.8	68.7	116.9	7.2
10/30/2002	16:01:00	70.2	22.0	108.1	4.1	46.9	67.9	117.0	7.2
10/30/2002	16:02:00	70.2	21.9	108.0	4.1	46.9	67.4	117.2	7.2
10/30/2002	16:03:00	70.2	21.7	108.0	4.0	46.8	67.3	117.3	7.2
10/30/2002	16:04:00	70.3	21.7	108.0	4.0	46.4	67.2	117.2	7.2
10/30/2002	16:05:00	70.3	21.8	107.7	3.6	46.2	68.1	116.8	7.2

Appendix B. Summary of Sample Data for Oct. 10, 2002, Case 4

Table B-1. Summary of Sample Data for Oct. 10, 2002, Case 4

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSloarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
1	14:15:00	9.1	108.9	39.1	73.9	41.9	77.0	9.9	108.1	34.4	77.0	23.0	88.5	26.3	24.3	72.1	31.1	5999
	14:16:00	8.7	109.4	38.6	74.4	45.8	77.1	10.5	106.7	35.1	77.0	23.5	88.4	26.8	24.5	72.0	31.1	7548
	14:17:00	7.7	115.9	38.5	74.5	47.7	75.5	12.4	108.2	35.6	76.7	25.4	87.2	27.8	24.5	72.0	32.9	8906
	14:18:00	7.0	117.1	38.6	74.0	45.5	74.1	12.1	107.5	35.5	75.2	29.3	82.1	32.3	24.7	72.2	36.5	10117
	14:19:00	6.6	116.9	38.8	73.9	43.7	73.3	11.7	107.2	35.6	73.6	31.9	77.9	35.9	24.5	72.2	37.4	10231
	14:20:00	6.5	115.7	39.0	73.7	42.2	72.7	11.3	107.6	35.6	72.2	32.7	75.6	37.1	24.7	71.7	37.2	10054
	14:21:00	6.4	115.3	39.9	73.0	41.0	72.5	10.4	107.9	35.5	71.0	33.7	74.0	38.4	24.6	71.3	36.7	9959
	14:22:00	6.5	114.3	40.1	72.8	40.0	72.4	11.4	108.2	35.3	70.2	34.2	73.1	39.4	24.3	71.6	36.5	9912
	14:23:00	6.4	114.3	40.5	72.7	39.2	72.4	10.5	108.6	34.9	69.6	34.3	72.8	40.1	24.3	71.5	35.6	9964
	14:24:00	6.5	113.7	40.4	72.7	37.2	72.6	10.2	108.9	34.6	69.3	34.7	72.7	40.7	24.6	71.4	35.5	10064
	14:25:00	6.4	113.7	39.3	73.2	36.6	73.2	9.3	109.6	34.2	69.0	34.0	72.9	39.8	24.8	71.8	35.0	10263
	14:26:00	6.5	113.6	38.7	73.7	36.2	73.3	8.7	109.7	33.9	69.0	33.3	73.3	39.0	24.7	72.2	34.5	10355
	14:27:00	6.4	113.8	38.6	74.0	36.5	73.3	7.9	110.1	33.6	69.0	33.1	73.5	38.9	24.4	72.4	34.0	10246
	14:28:00	6.4	113.5	38.5	74.2	37.0	73.3	7.2	109.8	33.2	68.9	32.8	73.8	38.7	24.5	72.5	33.5	10182
	14:29:00	6.3	113.5	38.5	74.4	37.0	73.0	7.1	110.3	32.9	68.9	32.5	73.9	38.6	24.5	72.4	32.9	10223
	14:30:00	6.3	113.4	38.6	74.2	36.9	72.7	7.1	109.8	32.6	69.0	32.8	73.9	39.0	24.1	72.5	32.6	10288
	14:31:00	6.3	113.4	37.9	74.4	36.7	72.7	7.1	110.2	32.3	69.0	32.3	74.0	38.5	23.9	72.6	32.3	10388
	14:32:00	6.3	113.3	38.5	74.5	36.6	72.7	7.1	109.7	32.1	69.0	32.1	74.0	38.4	23.9	72.5	31.9	10592
	14:33:00	6.3	113.1	38.6	74.5	36.4	72.7	7.1	110.3	32.0	69.0	32.2	74.0	38.7	24.0	72.6	31.7	10742
1	14:34:00	6.3	113.1	38.5	74.3	36.2	72.7	7.1	110.0	31.7	69.1	32.2	74.0	38.8	23.9	72.5	31.5	10862
																		9845

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
2	14:40:00	17.4	104.4	33.2	75.2	65.2	72.8	7.1	106.7	50.6	69.3	35.6	73.2	40.6	24.5	72.3	44.9	671
	14:41:00	19.2	101.4	23.7	75.9	67.3	73.2	7.1	105.5	52.3	69.5	35.4	73.6	40.0	23.9	72.8	46.0	633
	14:42:00	19.5	99.1	21.0	76.7	68.7	73.6	7.1	104.7	54.0	69.6	35.6	74.0	39.9	23.5	73.1	47.0	651
	14:43:00	22.5	97.1	18.7	77.6	69.3	74.0	7.1	103.6	55.0	69.9	35.6	74.2	39.6	23.8	73.2	47.6	639
	14:44:00	16.1	99.0	26.3	78.6	67.9	74.4	9.3	102.2	55.2	70.3	35.7	74.6	39.5	23.9	73.1	47.6	508
	14:45:00	10.9	115.6	34.8	78.5	54.8	75.4	20.9	104.3	48.4	70.9	34.8	74.9	39.0	24.0	73.4	42.5	6084
	14:46:00	7.8	122.0	36.6	77.5	47.4	76.5	23.6	104.1	43.0	71.5	34.3	75.1	39.0	23.6	73.3	38.9	11771
	14:47:00	7.0	122.0	37.1	76.7	43.8	76.8	22.2	103.7	39.9	71.7	33.8	75.1	38.9	23.5	73.0	36.8	12416
	14:48:00	6.8	120.1	37.8	76.0	41.8	76.8	21.3	103.6	38.0	71.7	33.6	75.1	39.0	23.3	72.9	35.5	12296
	14:49:00	6.7	118.6	38.2	75.5	40.9	76.6	20.5	103.5	36.9	71.7	33.7	74.9	39.5	23.3	72.6	34.8	12239
	14:50:00	6.7	117.1	38.4	75.1	40.1	76.2	19.5	103.4	36.0	71.7	33.3	74.7	39.2	23.3	72.5	34.1	12144
	14:51:00	6.8	116.0	38.9	75.0	39.4	75.8	19.4	103.4	35.2	71.7	33.6	74.6	39.9	23.5	72.5	33.6	12034
	14:52:00	6.8	115.0	38.7	75.0	39.0	75.6	19.4	103.5	34.7	71.5	33.4	74.5	39.7	23.6	72.7	33.2	11693
	14:53:00	6.9	114.2	38.9	74.8	38.5	75.4	19.1	103.5	34.3	71.4	33.5	74.3	40.0	23.5	72.7	33.0	11558
	14:54:00	6.9	113.7	38.5	75.0	38.2	75.2	19.1	103.5	34.0	71.2	33.1	74.5	39.4	23.6	73.1	32.6	11383
	14:55:00	6.9	113.4	38.2	75.0	37.9	75.2	18.9	103.5	33.7	71.2	32.7	74.6	38.9	23.5	73.0	32.3	11341
	14:56:00	6.8	113.2	38.2	75.0	37.6	74.9	19.0	103.7	33.5	71.2	32.7	74.6	39.1	23.4	72.9	32.1	11444
2	14:57:00	6.8	113.2	38.6	75.0	37.3	74.9	18.8	103.7	33.3	71.1	32.8	74.6	39.5	23.3	72.9	32.1	11555
																		8392

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
3	15:01:00	11.2	107.2	34.2	76.1	56.2	74.9	11.9	102.0	46.8	70.1	34.5	74.2	39.9	23.4	72.4	41.9	585
	15:02:00	9.4	105.0	23.5	77.0	60.6	74.9	8.3	99.8	50.3	69.9	35.4	74.1	40.8	23.7	72.5	44.6	519
	15:03:00	9.8	111.0	35.7	77.2	56.4	74.6	18.1	103.7	48.2	69.8	34.9	74.1	40.1	23.5	72.5	42.8	4957
	15:04:00	7.4	119.4	37.9	76.2	49.9	74.4	22.1	106.3	43.4	70.0	34.8	74.0	40.4	23.7	72.7	39.2	10578
	15:05:00	6.4	122.2	38.5	75.6	45.8	74.6	19.3	108.2	40.1	70.2	34.0	74.3	39.7	23.5	72.9	36.7	11594
	15:06:00	5.9	122.6	38.7	75.2	43.1	74.7	17.0	110.2	38.0	70.6	33.6	74.3	39.5	23.6	72.8	35.1	11899
	15:07:00	5.4	122.8	39.7	74.5	41.3	74.7	14.0	111.9	36.2	70.6	33.8	74.2	40.2	23.5	72.6	33.9	11746
	15:08:00	5.2	122.6	40.8	74.3	40.0	74.9	11.6	113.4	35.3	70.7	34.4	74.1	41.3	23.8	72.4	33.5	11622
	15:09:00	5.1	122.6	40.4	74.0	39.1	74.9	9.4	114.5	34.5	71.0	34.1	74.0	40.8	23.7	72.5	32.9	11556
	15:10:00	5.0	122.5	40.5	73.8	38.1	74.8	7.7	115.4	33.7	71.2	33.7	73.9	40.3	23.5	72.6	32.3	11492
	15:11:00	5.0	122.6	39.8	73.6	37.3	74.9	7.2	116.0	33.0	71.2	33.1	73.8	39.7	23.4	72.6	31.6	11579
	15:12:00	4.9	122.6	39.3	73.8	36.7	74.9	7.1	116.6	32.4	71.2	33.2	74.0	39.9	23.3	72.6	31.3	11707
	15:13:00	4.8	122.4	38.1	74.1	36.1	74.9	7.1	116.9	32.0	71.2	32.3	74.1	38.7	23.1	72.7	30.9	11816
	15:14:00	4.7	122.1	38.2	74.3	35.8	74.9	7.1	117.1	31.5	71.3	32.1	74.3	38.6	23.1	72.8	30.5	11602
	15:15:00	5.0	121.6	38.5	74.4	35.9	74.9	7.1	116.6	31.9	71.4	32.2	74.5	38.9	23.2	72.8	30.8	11547
3	15:16:00	10.5	117.2	38.9	74.7	39.3	75.2	7.1	115.0	33.7	71.0	32.9	74.3	39.6	23.9	72.6	32.6	10884
																		9730

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
4	15:28:00	42.6	73.7	18.8	85.0	57.5	71.2	7.1	98.9	60.6	59.2	34.3	73.5	38.8	24.4	72.0	47.5	6397
	15:29:00	44.9	72.6	18.5	85.7	58.2	70.7	7.1	98.5	62.7	58.9	34.4	73.5	38.8	24.6	72.1	48.6	6217
	15:30:00	48.8	71.7	18.1	86.2	62.0	70.5	7.1	98.3	67.4	58.9	34.7	73.5	38.7	24.3	72.1	50.0	6438
	15:31:00	41.5	76.7	21.5	86.5	62.4	70.0	7.9	100.1	65.8	59.1	34.9	73.4	39.1	24.4	72.2	49.2	7054
	15:32:00	16.0	104.6	29.5	84.0	60.8	69.5	15.8	106.4	61.4	59.6	34.3	73.5	38.3	23.7	72.0	46.5	8135
	15:33:00	8.5	116.4	34.4	80.6	58.4	68.8	18.7	106.1	58.5	60.4	34.5	73.5	38.9	23.8	71.9	44.7	8689
	15:34:00	6.7	119.2	36.3	78.1	56.3	69.0	19.6	105.3	55.5	61.3	34.3	73.2	38.8	23.7	71.9	43.2	9026
	15:35:00	6.2	119.5	38.3	76.4	54.6	69.2	20.3	104.5	52.9	62.2	34.9	73.0	40.0	23.6	71.9	42.4	9153
	15:36:00	6.0	119.3	39.0	75.4	53.3	69.5	20.7	104.1	51.1	62.9	34.8	72.9	40.1	23.9	71.6	41.6	9300
	15:37:00	5.9	118.9	40.2	74.7	52.0	69.8	21.0	103.8	49.5	63.5	35.3	72.9	40.9	23.9	71.4	41.1	9535
	15:38:00	5.8	118.6	40.2	74.1	50.9	70.1	21.3	103.8	48.0	64.1	35.0	72.9	40.5	24.3	71.5	40.3	9798
	15:39:00	5.7	118.4	40.2	73.9	49.7	70.3	21.3	103.8	46.6	64.6	34.7	72.9	40.2	24.4	71.7	39.5	9889
	15:40:00	5.6	118.2	39.8	73.9	48.4	70.6	21.2	103.9	45.3	65.1	34.7	72.9	40.3	24.1	71.7	38.8	9772
	15:41:00	5.6	117.9	40.5	73.5	46.9	70.7	21.0	104.2	43.8	65.5	34.6	72.9	40.5	24.1	71.7	37.9	9873
	15:42:00	5.4	117.9	40.1	73.4	45.4	71.1	20.5	104.7	42.2	65.9	34.3	72.9	40.2	24.5	71.8	36.9	9922
	15:43:00	5.3	117.8	39.6	73.7	44.1	71.3	20.1	105.1	40.8	66.3	34.1	73.0	40.1	24.5	71.9	36.1	10031
	15:44:00	5.2	117.8	38.3	73.9	42.9	71.6	19.1	105.6	39.6	66.6	33.2	73.4	39.1	24.3	72.1	35.2	10257
	15:45:00	5.1	117.6	39.0	74.2	41.9	71.7	17.9	105.9	38.6	67.0	33.1	73.5	39.2	24.2	72.3	34.6	10441
	15:46:00	5.1	117.1	39.2	74.0	41.1	71.9	17.3	106.4	37.9	67.1	33.0	73.5	39.3	24.0	72.0	34.0	10609
	15:47:00	5.0	117.1	39.3	73.9	40.6	72.0	16.4	107.0	37.2	67.5	33.1	73.3	39.6	23.9	71.8	33.8	10580
4	15:48:00	5.0	117.2	39.7	73.7	40.1	72.2	15.0	106.9	36.6	67.7	33.2	73.0	39.8	24.2	71.9	33.5	4915
																		8859

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
5	15:52:00	4.8	111.6	37.5	75.5	46.2	75.2	10.6	103.5	42.4	70.5	34.5	73.2	40.1	24.3	71.8	38.3	487
	15:53:00	4.5	109.6	36.8	76.0	48.5	75.8	7.9	102.4	44.5	70.7	34.5	73.5	39.6	24.1	71.9	40.1	365
	15:54:00	4.7	107.7	36.0	76.6	49.5	76.3	8.7	101.5	46.0	71.2	35.0	73.5	40.0	23.9	71.7	41.4	269
	15:55:00	7.2	110.0	35.6	76.8	48.1	76.9	12.9	103.7	45.6	71.4	35.2	73.5	40.1	24.3	71.8	41.6	4901
	15:56:00	7.1	119.2	38.4	75.6	44.6	76.8	17.4	107.2	42.3	71.3	34.9	73.4	40.3	24.5	71.9	39.2	10656
	15:57:00	6.4	121.1	39.4	74.5	42.5	76.3	15.0	108.1	40.0	71.2	34.7	73.0	40.4	24.3	71.8	37.5	11544
	15:58:00	6.3	119.9	39.4	73.9	41.2	75.9	14.2	108.1	38.3	71.2	34.4	72.9	40.1	24.1	71.8	36.0	11757
	15:59:00	6.2	118.7	39.2	73.5	40.1	75.6	13.0	108.4	37.3	71.0	33.8	72.9	39.5	24.0	71.8	35.0	11636
	16:00:00	6.2	117.7	39.8	73.4	39.1	75.3	12.7	108.3	36.4	70.7	33.9	72.9	40.0	24.0	71.8	34.4	11403
	16:01:00	6.3	116.5	39.8	73.4	38.6	75.0	11.6	108.5	35.8	70.6	34.3	72.9	40.6	23.8	71.6	34.0	11243
	16:02:00	6.3	115.7	39.4	73.4	38.1	75.0	10.4	108.3	35.3	70.5	33.8	72.9	39.9	23.5	71.5	33.5	11307
5	16:03:00	5.9	115.0	39.9	73.4	39.9	74.8	10.2	107.8	35.9	70.0	33.7	72.8	39.9	23.6	71.5	34.2	10730
																		8025

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
6	16:08:00	23.0	91.5	30.8	76.0	53.3	73.4	7.3	102.8	55.0	62.7	34.6	72.7	39.1	23.9	71.5	48.2	6827
	16:09:00	25.6	88.2	24.4	76.6	54.9	73.0	8.4	101.8	56.0	61.7	34.6	72.7	39.0	23.9	71.5	48.4	6758
	16:10:00	27.3	86.0	21.8	77.3	55.3	72.6	9.0	100.9	57.1	60.9	34.5	72.8	38.7	24.0	71.7	49.1	6581
	16:11:00	29.2	84.6	21.1	78.0	57.9	72.2	9.2	100.0	60.5	60.2	35.5	72.9	39.7	24.2	71.6	51.0	6736
	16:12:00	19.6	92.2	31.4	78.1	64.5	71.6	12.0	101.7	67.1	60.1	36.8	72.7	40.7	24.1	71.5	54.2	7049
	16:13:00	10.8	110.0	37.0	77.0	62.6	70.4	19.3	102.3	63.2	60.6	36.5	72.5	40.4	23.9	71.6	50.7	8252
	16:14:00	8.2	114.6	38.8	75.5	59.8	69.8	21.9	100.7	58.7	61.4	36.6	72.1	40.8	23.9	71.5	48.0	9015
	16:15:00	7.4	115.1	39.4	74.6	57.4	69.5	23.8	99.4	55.2	62.3	36.3	72.1	40.4	24.0	71.6	46.2	9399
	16:16:00	7.2	114.6	39.3	74.1	55.3	69.8	25.0	98.7	52.5	63.0	35.9	72.1	40.1	24.1	71.8	44.7	9638
	16:17:00	7.1	114.0	40.4	73.8	53.3	69.9	25.8	98.2	50.1	63.6	36.2	72.1	41.0	23.9	71.7	43.5	9592
	16:18:00	7.2	113.1	39.9	73.8	51.6	70.1	26.2	98.1	48.2	64.3	36.2	72.1	41.0	24.2	71.8	42.4	9601
	16:19:00	7.2	112.3	39.5	73.9	49.5	70.5	26.5	98.0	46.4	64.8	35.3	72.6	40.1	24.0	71.9	41.0	9620
	16:20:00	7.1	111.7	38.9	73.9	47.5	70.6	26.1	98.2	44.6	65.2	34.9	72.6	39.8	23.6	71.4	39.7	9743
	16:21:00	7.1	111.2	39.9	73.5	45.6	71.0	25.8	98.3	42.7	65.6	35.1	72.1	40.5	23.7	71.2	38.4	9945
	16:22:00	7.0	110.9	40.3	73.3	44.3	71.2	25.2	98.9	41.3	66.0	35.1	72.1	40.7	24.2	71.4	37.5	10194
6	16:23:00	7.0	110.7	41.6	73.0	43.2	71.4	24.8	99.3	40.1	66.2	35.5	72.0	41.5	24.6	71.8	36.9	10358
																		8707

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
7	16:28:00	7.3	107.1	59.1	73.2	54.2	72.9	26.0	99.7	49.2	67.9	51.9	70.1	65.7	46.5	69.0	46.2	825
	16:29:00	7.1	105.5	57.6	73.7	52.5	73.5	25.6	99.0	47.5	68.7	52.4	69.9	66.7	47.9	68.9	45.1	778
	16:30:00	7.1	103.9	56.2	74.3	50.8	74.2	24.7	98.3	46.2	69.5	52.2	69.9	66.2	48.3	68.5	44.2	705
	16:31:00	7.5	102.4	55.9	74.8	49.4	74.9	23.9	97.6	45.2	70.3	51.4	70.0	64.8	48.7	68.8	43.5	716
	16:32:00	7.9	101.0	54.9	75.3	48.3	75.6	24.4	97.0	44.4	70.9	50.6	70.4	63.5	48.4	68.9	42.9	725
	16:33:00	7.9	99.6	53.7	75.7	47.6	76.2	24.5	96.5	44.0	71.6	49.7	70.5	62.0	47.4	68.7	42.4	739
	16:34:00	10.4	99.4	53.1	76.0	50.6	76.8	26.6	96.7	46.4	72.0	50.6	70.5	62.8	46.8	68.8	44.6	765
	16:35:00	12.3	109.1	57.4	75.1	49.0	77.2	33.0	100.4	46.0	72.2	50.3	70.7	62.4	47.4	69.0	44.6	2332
	16:36:00	10.3	114.1	60.9	73.5	47.9	77.3	34.0	101.4	44.5	72.2	49.8	70.7	61.9	47.2	69.0	43.5	10028
	16:37:00	9.1	115.1	63.4	72.2	47.7	76.6	33.3	102.0	43.6	71.9	50.2	70.6	62.6	47.6	68.9	42.9	11954
	16:38:00	8.8	115.0	65.5	71.3	47.4	75.9	32.5	101.4	43.3	71.6	51.0	70.4	64.1	48.2	68.9	42.8	12014
	16:39:00	8.8	113.8	65.9	70.6	47.5	75.4	32.2	101.3	43.2	71.2	51.2	70.2	64.4	48.3	68.8	42.7	11880
	16:40:00	8.9	113.1	66.0	70.4	47.4	75.0	32.2	101.0	43.1	70.8	50.9	70.0	63.9	48.3	68.6	42.6	11773
	16:41:00	8.8	112.7	66.6	69.9	47.3	74.6	32.3	101.1	43.0	70.6	51.3	69.9	64.5	48.7	68.4	42.4	11699
	16:42:00	8.8	112.6	67.6	69.8	47.1	74.4	31.9	100.9	43.0	70.2	51.6	69.6	65.0	49.1	68.2	42.4	11622
	16:43:00	8.8	112.2	68.4	69.3	47.1	74.2	32.0	100.9	42.9	70.1	52.0	69.4	65.8	49.7	68.0	42.4	11530
	16:44:00	9.0	111.8	68.7	69.2	47.1	74.1	32.1	100.9	42.9	69.8	51.9	69.4	65.5	50.1	67.9	42.3	11472
	16:45:00	8.9	111.7	69.3	69.0	47.1	73.9	32.1	100.9	43.0	69.6	52.3	69.4	66.2	50.2	68.0	42.4	11459
	16:46:00	8.9	111.7	69.3	68.7	47.0	73.9	32.1	100.9	43.0	69.6	52.2	69.2	66.0	50.4	67.9	42.3	11441
	16:47:00	8.8	111.7	69.8	68.5	46.9	73.9	31.8	101.0	42.9	69.4	52.5	68.8	66.6	50.4	67.4	42.2	11410
	16:48:00	8.7	111.7	70.6	68.2	46.8	73.6	32.1	101.2	42.9	69.3	53.0	68.6	67.6	51.2	67.4	42.3	11415
	16:49:00	8.5	111.9	69.7	68.3	46.8	73.4	31.4	101.2	42.8	69.2	52.8	68.5	67.1	51.3	67.5	42.2	11423
7	16:50:00	8.7	111.7	69.3	68.5	46.7	73.3	31.5	101.1	42.9	69.0	52.7	68.5	66.8	51.4	67.7	42.3	11373
																		7829

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
8	11:33:00	34.7	76.6	33.9	79.1	43.9	73.9	24.8	88.2	42.6	66.6	37.2	70.3	42.7	28.0	68.9	38.9	2320
	11:34:00	34.4	76.6	34.1	79.2	43.6	73.9	23.6	88.5	42.2	67.0	36.9	70.5	42.3	28.2	69.0	38.5	2191
	11:35:00	34.7	76.8	32.4	79.2	43.3	74.0	26.0	88.7	41.7	67.2	36.6	70.5	42.0	28.1	68.9	38.2	2226
	11:36:00	35.6	76.7	33.3	79.2	44.1	74.2	25.4	89.0	42.6	67.6	36.5	70.5	41.6	28.1	69.0	38.7	2243
	11:37:00	36.9	76.4	32.1	79.2	46.6	74.3	27.4	89.3	44.6	67.6	36.5	70.7	41.4	28.1	69.1	40.4	2285
	11:38:00	36.1	77.9	32.1	79.0	44.6	74.5	34.3	90.8	43.3	67.6	36.4	70.8	41.5	27.7	69.0	39.4	3722
	11:39:00	24.9	90.4	35.0	77.2	44.2	73.8	44.7	94.6	40.6	67.7	36.0	70.9	41.6	27.7	69.1	37.8	8889
	11:40:00	14.0	102.9	36.1	75.4	42.9	72.9	39.9	96.7	38.2	67.9	35.0	71.1	40.5	27.4	69.4	35.7	10162
	11:41:00	9.6	108.6	36.4	74.6	41.2	72.3	34.7	99.5	36.3	67.9	34.7	71.5	40.3	27.3	69.7	34.4	10322
	11:42:00	7.6	111.8	36.9	74.4	39.7	72.1	29.4	102.7	34.8	67.9	34.2	71.9	39.9	27.9	70.0	33.0	10245
	11:43:00	6.8	113.6	36.9	74.0	38.3	72.2	24.3	106.8	33.5	68.3	33.7	72.2	39.5	28.0	70.1	31.9	10174
	11:44:00	6.3	114.8	38.1	73.7	37.2	72.3	18.2	109.5	32.6	68.4	33.8	72.2	40.0	27.9	70.2	31.3	10159
	11:45:00	6.0	115.1	38.4	73.1	36.6	72.3	14.0	111.8	31.9	68.5	33.5	72.1	39.8	26.9	69.9	30.7	10340
	11:46:00	5.6	115.6	38.4	72.4	35.9	72.3	9.8	113.2	31.1	68.7	32.9	71.7	39.2	27.0	70.0	30.1	10540
	11:47:00	5.4	115.7	38.8	71.9	35.1	72.3	7.6	113.9	30.6	68.7	33.2	71.4	39.8	26.1	70.0	29.8	10633
	11:48:00	5.3	116.0	38.8	71.8	34.3	72.5	7.3	115.0	30.6	68.7	33.4	71.3	40.2	26.6	69.9	30.2	10088
8	11:49:00	5.2	116.4	37.3	71.8	33.3	72.9	7.2	115.4	30.2	68.8	32.5	71.3	38.8	26.5	69.9	29.7	3286
																		7049

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
9	11:58:00	31.4	82.0	33.0	75.9	55.7	72.9	7.1	104.3	58.2	62.0	34.9	71.6	38.7	25.7	70.4	50.6	7361
	11:59:00	32.5	80.8	33.0	76.2	56.3	72.5	7.1	103.6	58.4	61.1	34.8	71.6	38.6	25.9	70.5	50.1	7776
	12:00:00	29.8	80.8	32.9	76.4	53.2	72.3	7.1	103.0	55.3	60.8	35.2	71.6	39.7	25.5	70.3	47.6	8035
	12:01:00	30.4	80.0	33.1	76.7	50.5	72.1	7.1	102.4	53.4	60.7	35.0	71.6	39.5	25.7	70.0	46.3	8029
	12:02:00	26.5	80.2	33.4	77.0	51.7	71.9	7.1	102.1	55.3	60.3	35.5	71.4	40.1	26.1	69.9	47.6	7633
	12:03:00	13.6	98.9	36.2	76.4	52.4	70.9	7.1	109.6	54.8	60.2	36.4	71.3	41.3	26.3	69.9	47.6	7591
	12:04:00	8.9	111.3	37.8	74.9	51.7	69.6	7.2	109.1	52.5	60.5	35.3	71.4	39.8	26.5	70.3	44.8	8600
	12:05:00	7.4	113.7	38.7	73.6	50.5	69.4	7.3	108.4	50.4	61.3	35.5	71.3	40.4	26.2	70.3	42.8	9449
	12:06:00	7.1	114.5	38.4	73.1	49.2	69.7	8.5	107.2	48.4	62.3	35.4	71.4	40.4	26.2	70.2	41.7	9925
	12:07:00	6.9	114.6	38.4	73.0	48.3	70.0	9.0	106.8	46.6	63.1	34.7	71.7	39.6	26.5	70.5	40.6	10180
	12:08:00	6.9	114.5	39.3	72.8	47.5	70.4	9.6	106.2	45.2	63.8	34.7	71.9	40.0	26.5	70.9	39.7	10222
	12:09:00	6.9	114.0	39.2	72.6	46.6	70.6	9.9	106.1	44.0	64.4	34.8	71.9	40.3	26.7	71.3	39.0	10077
	12:10:00	6.9	113.8	40.3	72.4	45.2	70.8	10.2	105.9	42.5	65.0	35.0	71.7	40.9	26.6	71.2	38.0	10113
	12:11:00	6.8	113.7	40.8	72.3	43.5	71.2	10.3	106.3	40.9	65.4	35.3	71.6	41.6	26.0	70.8	36.9	10199
	12:12:00	6.7	113.4	39.7	72.3	41.8	71.6	10.0	106.6	39.1	65.9	34.8	71.6	41.1	26.0	70.6	35.6	10398
	12:13:00	6.6	112.9	40.1	72.3	40.4	71.7	9.0	107.0	37.7	66.3	34.5	71.7	40.8	26.1	70.6	34.7	10710
	12:14:00	6.5	112.9	39.8	72.3	39.2	72.0	8.5	107.7	36.6	66.6	34.3	71.9	40.9	26.6	70.8	33.9	10927
9	12:15:00	6.4	112.9	40.0	72.3	38.4	72.2	7.5	108.3	35.7	67.1	34.3	71.9	41.0	26.5	70.9	33.4	11085
																		9351

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
10	12:47:00	6.2	119.1	38.7	75.1	38.7	80.3	17.2	106.7	36.2	76.6	34.0	74.9	40.2	26.3	72.5	34.2	9984
	12:48:00	7.5	117.2	37.6	75.6	42.6	80.4	17.9	106.3	43.0	74.5	34.8	74.7	40.3	25.7	72.3	41.8	10507
	12:49:00	7.7	114.9	37.3	75.9	46.2	80.4	18.2	105.8	51.8	71.7	35.7	74.3	40.4	25.4	72.1	48.9	10045
	12:50:00	9.9	112.7	36.6	76.4	51.5	80.3	17.8	105.4	62.6	69.2	37.0	73.8	40.4	25.5	71.8	57.5	9982
	12:51:00	11.4	110.0	35.8	76.9	55.8	80.1	16.6	105.3	67.6	67.7	38.1	73.2	41.0	25.9	71.9	60.0	10847
	12:52:00	8.5	119.1	35.9	76.7	55.8	78.6	18.9	106.9	61.2	67.3	37.4	73.0	40.5	25.8	72.0	53.6	11436
	12:53:00	6.9	125.1	37.6	75.9	54.4	76.7	23.0	104.0	54.9	67.7	37.0	73.1	40.5	25.6	72.0	48.4	11257
	12:54:00	6.5	125.0	38.7	75.6	52.2	75.7	25.0	102.5	50.2	68.1	36.6	73.5	40.5	25.8	72.2	45.0	11089
	12:55:00	6.2	124.0	38.3	75.5	49.6	75.2	27.1	101.5	46.3	68.7	36.1	73.7	40.4	26.1	72.5	41.9	11075
	12:56:00	6.1	122.8	38.3	75.1	46.9	75.2	27.2	101.2	42.8	69.2	35.3	73.8	39.8	26.1	72.4	39.0	11240
	12:57:00	6.0	121.6	38.9	74.9	44.5	75.2	27.1	101.1	40.3	69.8	35.4	73.5	40.6	26.3	72.6	37.0	11581
	12:58:00	6.0	120.6	39.2	74.7	42.7	75.2	26.9	101.6	38.2	70.4	35.1	73.6	40.5	25.9	73.1	35.3	11802
	12:59:00	5.9	120.0	38.7	74.9	41.1	75.4	26.1	101.9	36.7	70.7	34.9	73.8	40.7	25.6	72.9	34.2	11989
	13:00:00	5.9	119.4	38.9	75.0	39.8	75.5	25.6	102.5	35.5	71.2	34.4	74.1	40.5	25.5	72.7	33.1	12132
	13:01:00	5.7	119.2	39.0	75.0	38.8	75.7	24.4	103.0	34.4	71.4	34.0	74.1	40.3	25.7	72.8	32.2	12192
	13:02:00	5.7	118.7	38.4	74.9	38.0	75.7	23.4	103.3	33.4	71.7	33.6	74.1	39.8	25.3	72.7	31.3	12061
	13:03:00	5.5	118.5	39.5	74.5	37.4	75.7	22.4	103.8	32.7	71.7	34.1	74.0	40.9	25.2	72.2	31.1	11788
	13:04:00	5.6	118.0	39.9	74.4	36.9	75.7	21.7	104.0	32.2	72.0	33.9	74.0	40.8	25.2	71.8	30.5	11644
	13:05:00	5.5	117.8	40.3	74.4	36.6	75.7	21.1	104.6	31.8	72.1	34.3	73.9	41.6	25.7	71.9	30.4	11539
	13:06:00	5.4	118.1	39.2	74.4	36.1	75.7	20.5	104.8	31.4	72.3	33.6	74.1	40.7	25.5	72.1	30.0	11621
	13:07:00	5.3	118.0	39.6	74.6	35.8	75.7	19.8	105.0	31.1	72.3	33.6	74.3	40.8	25.7	72.4	29.9	11843
	13:08:00	5.3	118.1	38.4	75.1	35.6	75.7	19.6	105.4	31.0	72.3	32.9	74.7	39.8	26.0	73.2	29.8	12049
	13:09:00	5.2	118.1	38.3	75.5	35.3	75.7	18.8	105.7	30.8	72.3	32.6	75.1	39.4	25.8	73.9	29.6	12227
	13:10:00	5.2	117.9	37.2	75.5	35.0	75.7	18.1	105.8	30.4	72.3	31.8	75.0	38.3	25.4	73.8	29.2	12305
10	13:11:00	5.1	117.7	38.3	75.1	34.7	75.7	17.1	105.9	30.2	72.3	32.4	74.6	39.4	24.7	73.3	29.2	12301
																		11461

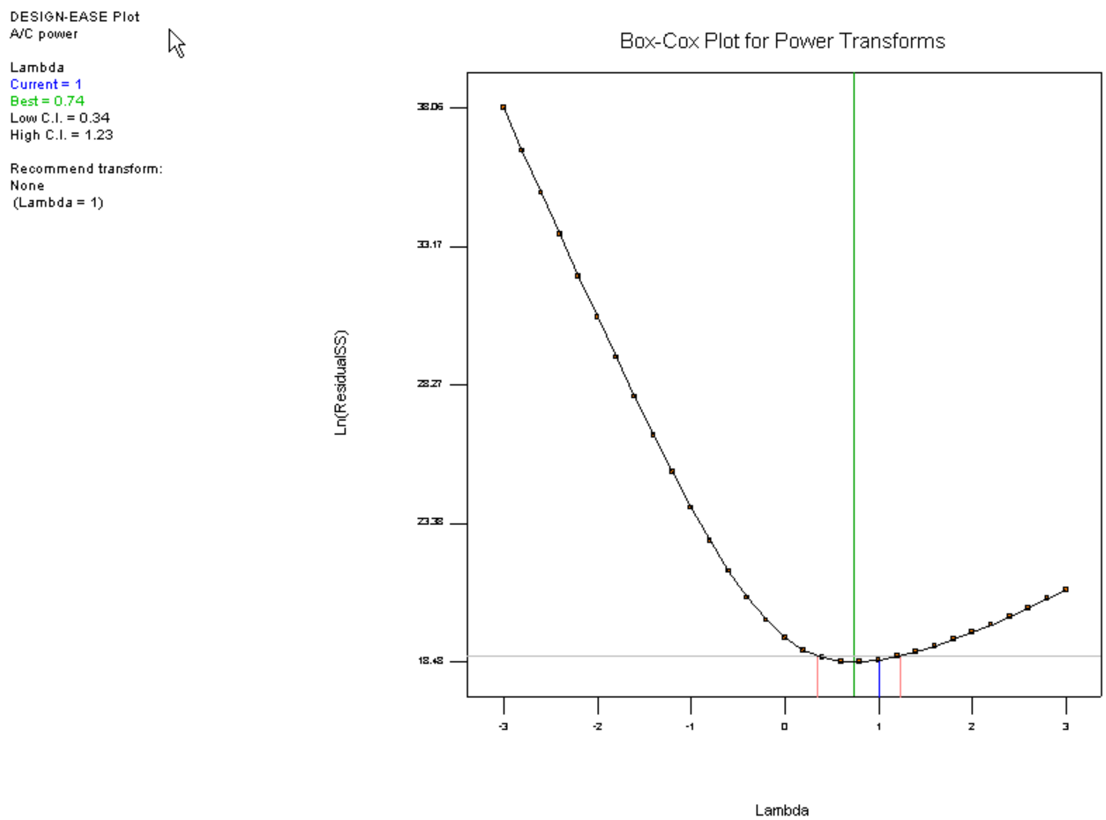
	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
11	13:15:00	6.6	116.5	37.7	75.3	36.3	75.5	18.2	105.8	36.7	70.3	33.3	74.0	40.0	25.1	73.0	35.6	10286
	13:16:00	7.9	114.3	37.7	75.8	46.3	75.7	16.3	105.4	49.9	68.1	35.2	73.7	40.7	25.2	72.6	47.1	8602
	13:17:00	10.4	111.1	37.0	76.5	48.7	75.7	15.6	105.0	51.6	66.0	35.6	73.4	40.8	24.8	72.2	48.8	8643
	13:18:00	9.9	108.0	35.9	77.2	43.4	76.0	12.8	104.8	49.5	64.7	35.5	73.4	41.2	24.7	71.8	46.5	9342
	13:19:00	6.8	112.0	35.8	77.3	44.0	75.4	17.2	106.2	51.8	64.1	35.4	73.5	40.1	24.9	71.7	47.1	9764
	13:20:00	6.2	118.0	37.7	76.5	47.7	73.8	20.8	105.4	51.6	64.3	35.6	73.5	40.1	25.3	72.1	45.8	10503
	13:21:00	6.0	119.8	39.7	76.0	48.4	73.2	21.7	104.6	49.3	64.9	36.2	73.5	41.2	25.4	72.5	44.0	10575
	13:22:00	5.8	120.4	41.1	75.6	47.4	72.7	22.2	103.7	46.0	65.7	36.3	73.7	41.8	25.7	72.6	41.5	10646
	13:23:00	5.7	120.0	38.6	75.5	45.1	73.1	23.6	103.1	42.2	66.6	34.6	74.0	39.7	25.9	73.1	38.1	10759
	13:24:00	5.5	119.3	40.0	75.5	42.6	73.3	23.8	102.8	39.3	67.4	35.0	74.1	41.1	25.9	73.6	35.9	10988
	13:25:00	5.6	118.4	39.4	75.8	40.9	73.7	23.5	103.0	37.3	68.2	34.4	74.4	40.6	25.1	73.4	34.3	11221
	13:26:00	5.5	117.8	39.6	75.8	39.5	74.0	23.0	103.4	35.6	68.9	34.5	74.6	41.1	25.0	73.3	33.1	11278
	13:27:00	5.5	117.5	38.8	75.7	38.6	74.3	21.5	103.7	34.3	69.6	33.4	74.6	39.8	25.2	73.2	32.0	11412
	13:28:00	5.3	117.1	39.4	75.4	37.9	74.4	20.5	104.0	33.3	70.0	33.6	74.5	40.4	25.1	73.0	31.2	11478
11	13:29:00	5.4	116.8	39.9	75.3	37.4	74.4	20.4	104.2	32.6	70.5	33.7	74.4	40.9	25.3	73.2	30.8	11340
																		10456

	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
12	13:32:00	5.6	116.4	40.3	75.3	47.4	74.5	20.9	104.4	43.2	70.3	35.0	74.5	41.2	25.2	73.1	40.1	9927
	13:33:00	10.5	114.7	39.5	75.7	54.8	74.4	20.1	104.1	53.2	68.1	36.2	74.6	41.7	25.6	73.3	50.1	8565
	13:34:00	11.2	110.9	44.1	76.2	53.7	74.4	17.3	103.7	56.1	66.0	40.5	74.4	48.1	28.4	72.9	53.6	8617
	13:35:00	7.3	115.5	49.7	75.9	54.7	73.6	21.8	105.9	58.3	65.0	43.3	73.7	51.8	32.7	72.0	53.4	9477
	13:36:00	6.9	120.3	52.2	75.1	56.1	72.7	25.4	104.7	57.3	65.1	44.2	73.1	52.7	36.0	71.7	51.2	10322
	13:37:00	6.7	120.8	53.4	74.4	55.4	72.4	27.4	103.6	54.5	65.6	44.2	73.0	52.8	36.7	71.4	49.0	10744
	13:38:00	6.7	121.0	53.7	74.0	53.7	72.5	29.5	102.7	51.1	66.2	44.0	73.2	52.9	37.0	71.2	46.8	11036
	13:39:00	6.6	120.3	54.5	73.7	51.0	72.8	30.3	102.3	47.7	66.9	44.3	73.1	53.8	38.0	71.2	44.3	11215
	13:40:00	6.6	119.5	53.5	73.3	48.3	73.2	30.4	101.9	44.9	67.6	43.7	73.0	53.1	37.7	71.3	42.0	11369
	13:41:00	6.6	118.5	54.4	73.3	46.5	73.5	30.5	102.1	42.9	68.2	44.0	73.0	54.1	38.3	71.3	40.6	11485
	13:42:00	6.6	118.3	55.8	73.3	45.3	73.8	30.7	102.6	41.5	68.8	44.3	73.1	55.1	39.6	71.1	39.6	11567
	13:43:00	6.6	118.1	55.6	73.3	44.3	74.0	29.8	103.1	40.4	69.3	44.3	73.0	55.3	40.5	71.0	38.8	11621
	13:44:00	6.7	117.9	57.4	73.3	43.6	74.3	29.5	103.4	39.8	69.6	44.9	73.0	56.6	41.0	71.0	38.4	11699
	13:45:00	6.6	117.7	56.9	73.3	43.1	74.4	29.1	103.9	39.3	70.0	44.3	73.5	55.7	42.0	71.2	38.1	11713
	13:46:00	6.6	117.8	55.1	73.3	42.5	74.6	28.3	104.1	38.6	70.2	43.7	73.3	54.7	40.7	71.0	37.4	11699
	13:47:00	6.4	117.9	55.6	73.3	42.0	74.7	27.3	104.2	38.1	70.6	43.8	73.0	55.2	41.1	71.0	37.1	11733
12	13:48:00	6.5	117.6	55.0	73.1	41.6	74.9	26.9	104.2	37.7	70.6	43.5	73.0	54.7	40.4	70.9	36.8	11723
																		10854

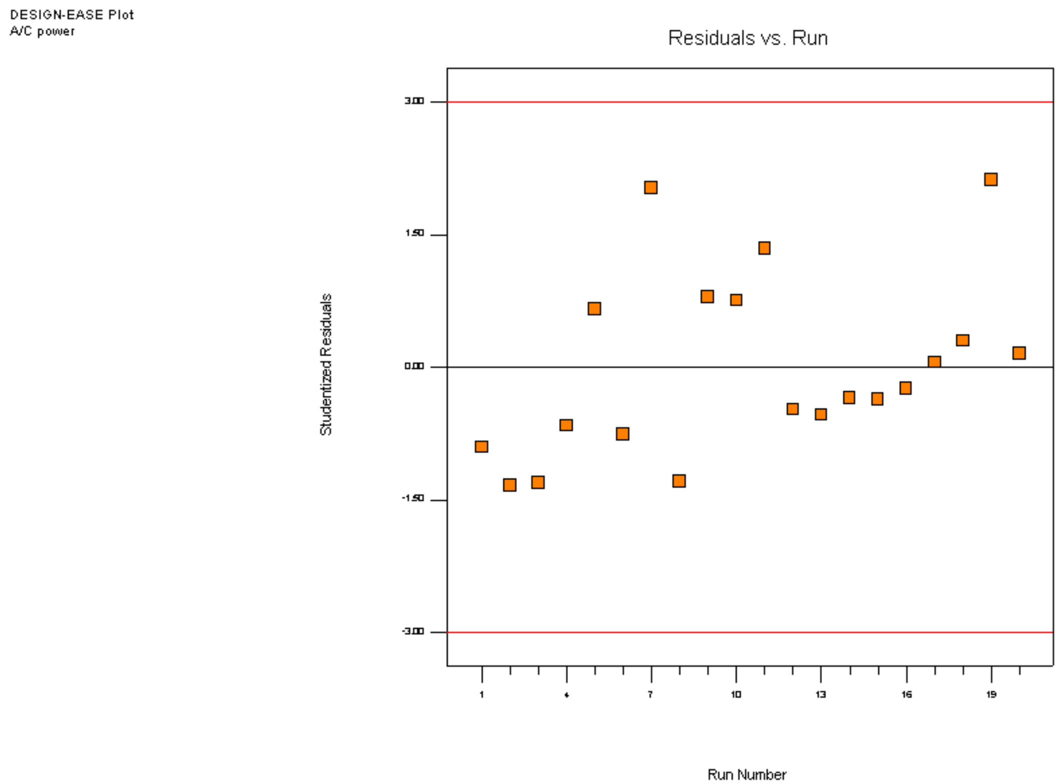
	Time	Dporh RH%	Dpot °F	Drirh RH%	Drit °F	Dpirh RH%	Dpit °F	Drorh RH%	Drot °F	GRIzrh RH%	GRIzat °F	GROrh RH%	GROat °F	GSIoarh RH%	oarh RH%	oat °F	GSOrh RH%	A/C Power Btu/hr
13	13:57:00	33.2	92.1	27.8	78.7	58.8	77.9	18.6	102.2	57.6	70.7	48.4	72.8	59.1	42.0	70.9	52.3	467
	13:58:00	33.8	90.1	25.5	79.9	55.3	78.4	18.8	101.9	54.5	71.3	47.2	73.0	57.4	41.7	70.9	49.3	456
	13:59:00	34.4	88.8	29.6	80.6	51.9	79.0	21.0	101.7	51.4	72.0	47.8	73.0	58.8	42.5	70.8	47.2	428
	14:00:00	35.3	87.8	26.6	81.1	49.5	79.8	22.8	101.5	49.1	72.8	48.4	73.0	60.1	44.1	70.8	45.8	425
	14:01:00	37.8	87.4	28.4	81.8	53.1	80.4	22.7	101.6	53.1	73.4	48.2	73.4	59.0	43.4	70.9	49.0	439
	14:02:00	20.1	107.4	48.6	80.5	51.5	80.8	27.5	108.5	50.1	73.6	48.3	73.5	59.6	43.9	71.1	47.5	6744
	14:03:00	10.4	125.1	58.9	77.0	48.1	80.6	27.2	111.6	45.9	73.9	48.8	73.4	61.3	45.4	71.0	44.4	12692
	14:04:00	7.6	129.8	61.9	74.5	46.1	80.3	21.7	114.0	43.4	74.2	49.0	73.0	62.2	46.5	70.5	42.5	13271
	14:05:00	6.9	129.7	63.9	72.7	45.4	79.8	19.4	114.7	41.8	74.5	49.5	72.8	63.1	46.5	70.3	41.7	13121
	14:06:00	6.6	129.2	65.0	71.6	45.2	79.2	16.2	115.7	40.8	74.5	49.3	72.6	63.1	46.7	70.1	41.1	12860
	14:07:00	6.6	128.2	66.9	70.7	44.8	78.6	14.5	115.2	40.3	74.5	49.9	72.1	64.1	47.7	70.1	41.0	12757
	14:08:00	6.5	126.9	66.7	70.4	44.3	78.3	13.8	115.7	40.2	74.2	50.1	72.1	64.5	47.4	70.2	41.4	12737
	14:09:00	6.6	126.3	65.8	70.6	44.5	77.9	12.9	115.5	40.1	73.9	49.4	72.1	63.5	47.4	70.0	41.1	12651
	14:10:00	6.6	125.4	62.8	70.6	44.7	77.6	12.0	115.3	40.0	73.9	48.8	72.2	62.3	46.3	70.0	40.8	12577
	14:11:00	6.6	125.1	63.7	71.0	44.3	77.3	12.0	115.1	39.7	73.7	48.2	72.6	61.5	46.5	70.1	40.5	12606
	14:12:00	6.6	124.9	64.8	70.7	44.1	77.3	11.5	115.0	39.5	73.5	48.6	72.7	62.1	47.0	70.1	40.4	12591
	14:13:00	6.7	124.5	64.4	70.8	43.8	77.3	12.3	115.2	39.4	73.4	48.2	72.7	61.6	47.0	70.0	40.2	12594
	14:14:00	6.6	124.5	65.5	70.6	43.6	77.3	12.1	115.4	39.3	73.4	48.3	72.7	61.7	47.2	69.7	40.1	12574
13	14:15:00	6.6	124.3	64.5	70.6	43.4	77.3	11.9	115.4	39.2	73.4	48.3	72.6	61.8	46.8	70.0	40.1	12499
																		9184

	Time	Dporh	Dpot	Drirh	Drit	Dpirh	Dpit	Drorh	Drot	GRIzrh	GRIzat	GROrh	GROat	GSIoarh	oarh	oat	GSOrh	A/C Power
		RH%	°F	RH%	°F	RH%	°F	RH%	°F	RH%	°F	RH%	°F	RH%	RH%	°F	RH%	Btu/hr
14	14:18:00	12.6	115.7	60.8	72.2	41.2	77.1	7.9	113.1	42.0	70.2	46.7	72.6	58.9	44.7	70.1	44.3	11052
	14:19:00	14.4	110.4	57.3	73.1	46.9	77.1	7.2	111.9	50.4	68.5	47.2	72.4	58.5	44.9	70.1	50.6	10082
	14:20:00	8.8	113.4	57.0	73.4	51.4	76.3	10.2	112.4	56.6	67.0	48.2	72.2	59.3	45.2	70.1	54.7	10002
	14:21:00	7.3	121.3	59.5	72.8	54.7	74.9	16.1	110.8	57.2	66.6	48.3	72.2	59.2	44.9	70.1	52.6	10905
	14:22:00	6.9	123.8	61.9	72.4	54.7	74.3	18.4	109.7	55.0	67.1	48.4	72.3	59.4	45.4	70.1	50.4	11338
	14:23:00	6.7	124.4	61.4	72.0	53.4	74.3	20.7	108.6	51.9	67.6	47.9	72.6	58.9	44.8	69.9	48.2	11551
	14:24:00	6.6	124.3	61.5	71.7	51.4	74.3	21.3	108.2	48.7	68.1	47.5	72.7	58.7	44.9	69.7	45.8	11694
	14:25:00	6.6	123.6	62.5	71.6	49.2	74.6	21.9	107.8	46.1	68.7	47.6	72.7	59.3	45.9	69.8	43.9	11796
	14:26:00	6.6	122.7	63.4	71.3	47.6	74.9	22.0	107.9	44.2	69.3	47.7	72.4	59.9	45.4	69.6	42.5	11909
	14:27:00	6.6	122.2	64.8	71.0	46.7	75.1	22.3	107.9	43.0	69.8	48.1	72.2	61.1	46.7	69.3	41.8	11943
	14:28:00	6.6	121.8	66.1	70.6	46.0	75.2	22.1	108.5	42.2	70.3	48.7	72.2	62.3	48.0	69.3	41.5	12034
	14:29:00	6.7	121.8	67.9	70.4	45.5	75.4	22.0	109.0	41.7	70.6	49.6	72.1	64.2	48.8	69.3	41.4	12080
	14:30:00	6.6	121.6	68.0	70.3	45.3	75.4	21.3	109.2	41.4	70.8	50.0	71.7	65.1	49.3	69.3	41.2	12077
	14:31:00	6.6	121.5	67.4	70.3	45.1	75.1	21.4	109.3	41.1	71.2	49.4	71.7	64.2	49.6	69.4	40.9	12072
	14:32:00	7.1	121.1	67.0	70.2	50.3	75.5	22.2	108.9	45.4	71.0	49.7	71.6	64.1	49.0	69.1	44.7	11430
	14:33:00	12.9	117.3	65.7	70.6	48.3	75.4	20.3	108.3	45.5	69.6	49.6	71.6	64.1	49.1	69.2	47.3	10642
	14:34:00	14.1	110.8	63.4	71.5	45.7	75.3	17.3	107.6	46.1	68.0	49.4	71.1	63.7	48.0	69.5	47.9	10443
	14:35:00	15.3	105.2	60.9	72.5	44.2	75.2	16.0	106.9	46.7	66.6	50.1	70.6	64.5	47.0	69.2	48.6	10119
	14:36:00	17.1	99.8	49.7	73.6	43.1	75.2	13.6	106.1	47.3	65.2	48.6	70.8	61.8	47.1	69.4	48.8	9753
14	14:37:00	18.9	95.1	46.7	74.7	42.4	75.2	12.8	105.1	47.9	64.1	48.9	71.0	61.9	47.0	69.4	49.0	9480
																		11120

Appendix C. Additional Analytic Results for Task 6 Case 1



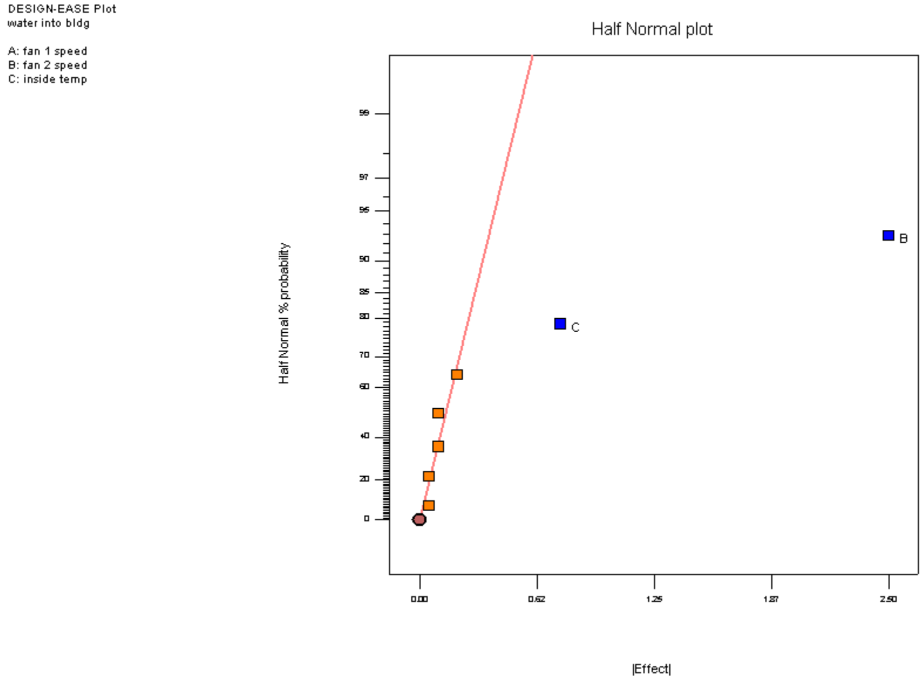
This plot provides information for selecting a power law transformation. The transformation listed is based on the best lambda value, which is found at the minimum point of the curve generated by the natural log of the sum of squares of the residuals. If the 95% confidence interval around this lambda includes 1, then there is no need for a transformation.

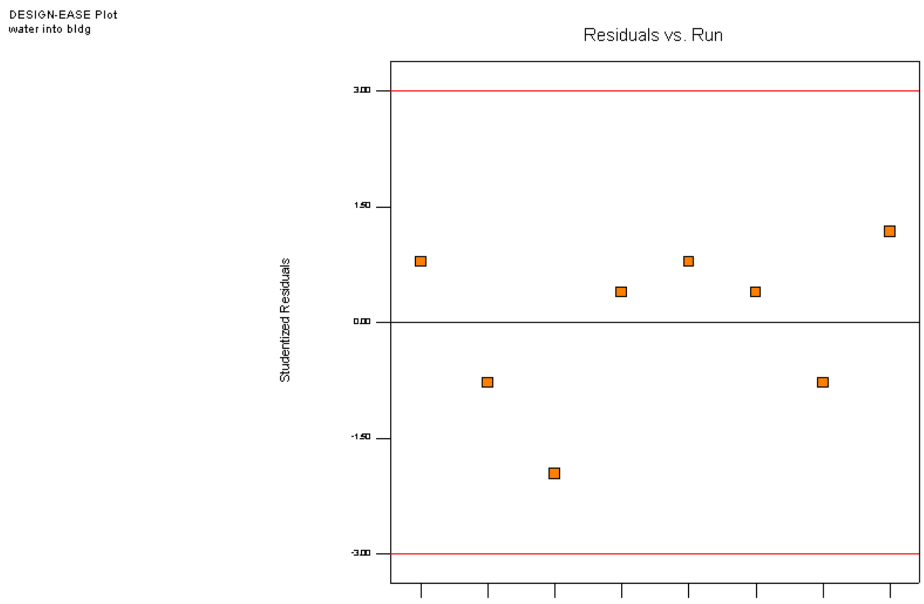


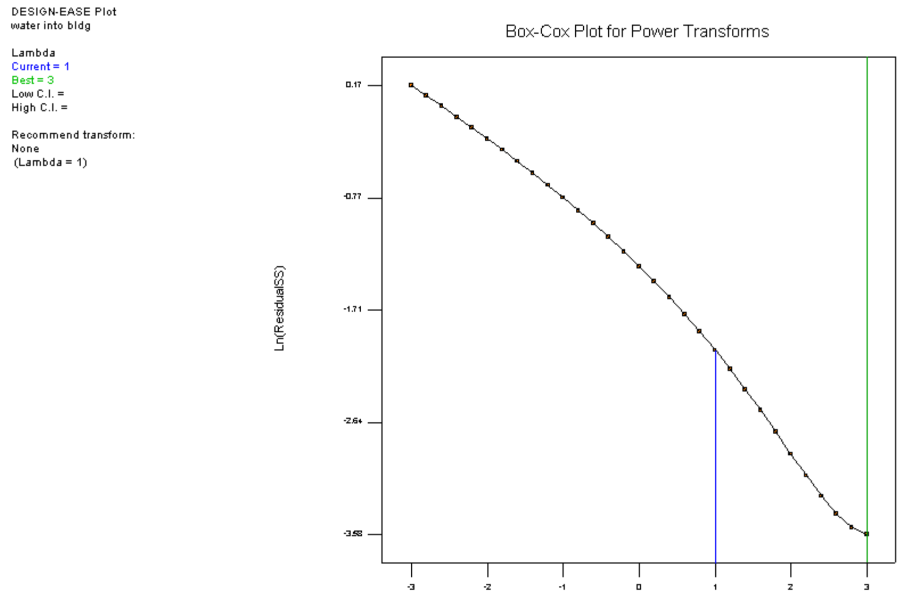
The residuals versus run plot shows the residuals versus the experimental run order. It can be used to see if any unexpected variables influenced the response during the experiment. It should show a random scatter. Trends indicate a time-related variable in the background.

Appendix D. Additional Analytic Results for Task 6 Case 2

Response 2

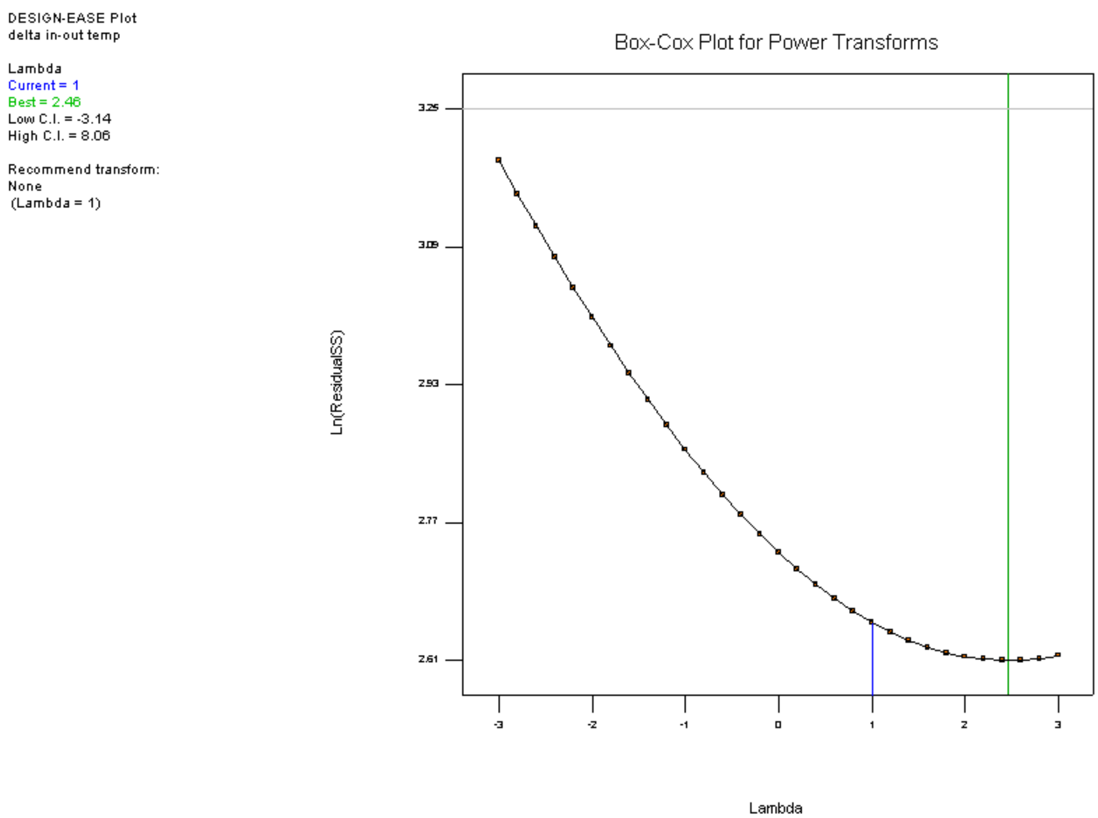






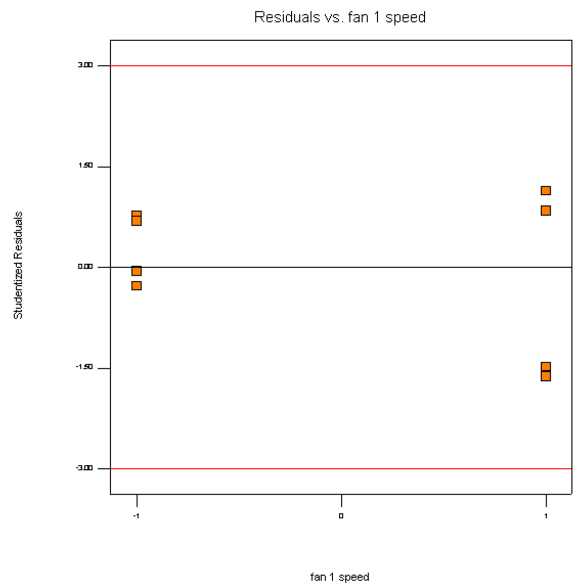
DESIGN-EASE Plot
water into bldg
Lambda
Current = 1
Best = 3
Low C.I. =
High C.I. =
Recommend transform:
None
(Lambda = 1)
Box-Cox Plot for Power Transforms
Ln(ResidualSS)
0.17
-0.77
-1.71
-2.64
-3.58
-3
-2
-1
0
1
2
3

Response 5



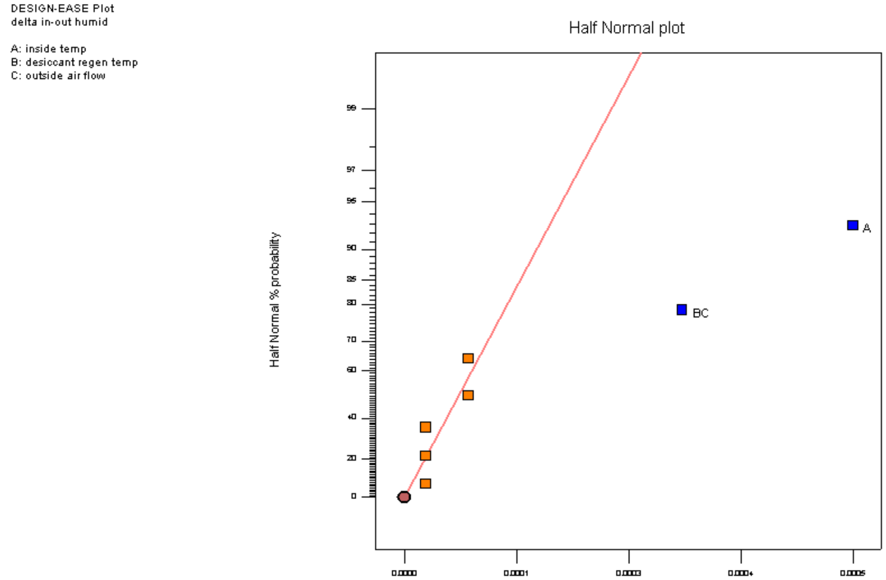
DESIGN-EASE Plot
delta in-out temp
Lambda
Current = 1
Best = 2.46
Low C.I. = -3.14
High C.I. = 8.06
Recommend transform:
None
(Lambda = 1)
Box-Cox Plot for Power Transforms
Ln(ResidualSS)
3.25
3.09
2.93
2.77
2.61
-3
-2
-1
0
1
2
3
Lambda

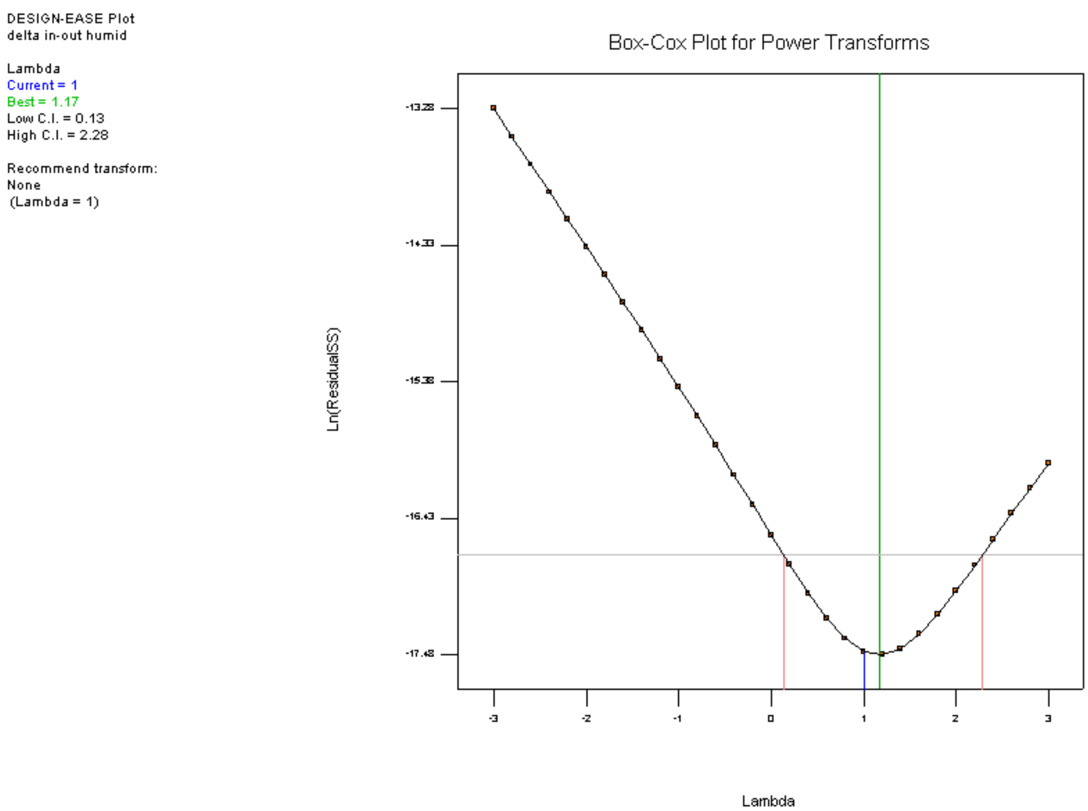
DESIGN-EASE Plot
delta in-out temp

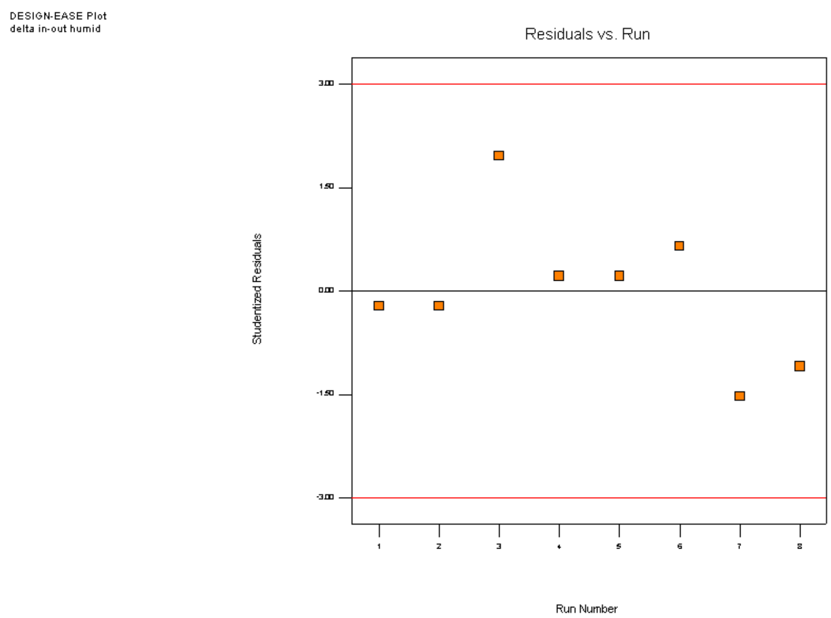


Appendix E. Additional Analytic Results for Task 6 Case 3

Response 1

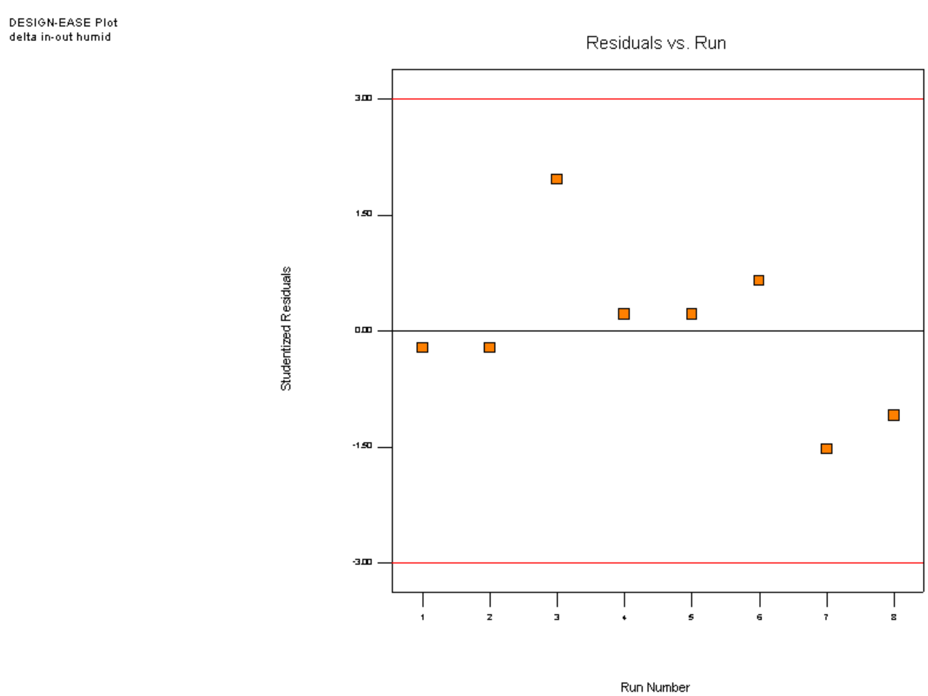




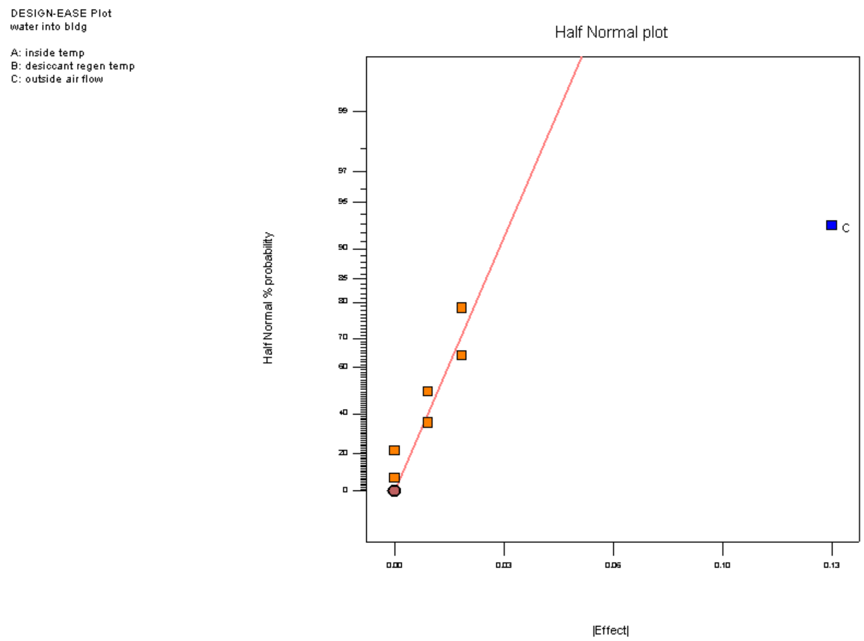


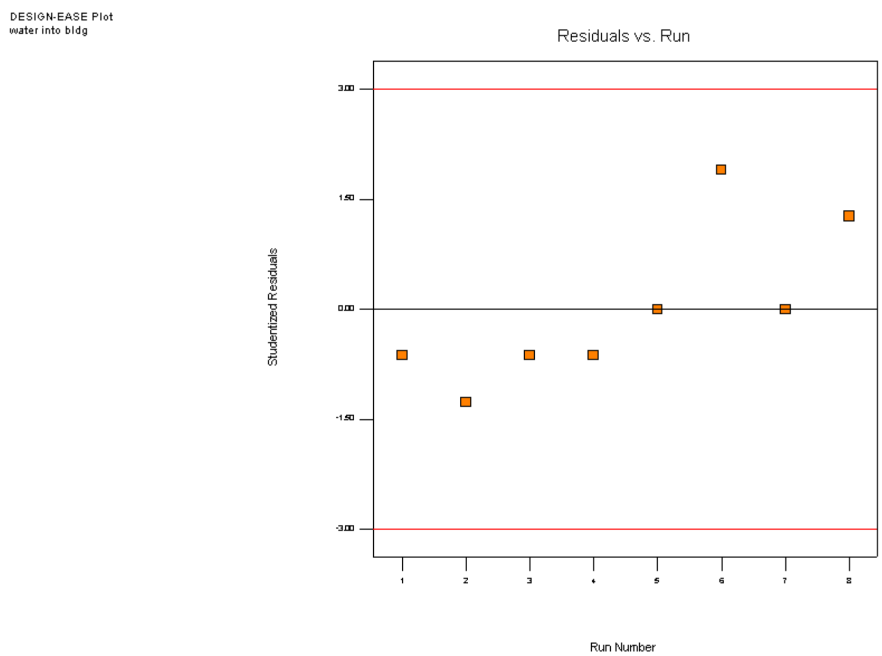
DESIGN-EASE Plot
delta in-out humid
Residuals vs. Run
Studentized Residuals
3.00
1.50
0.00
-1.50
-3.00
1
2
3
4
5
6
7
8
Run Number

Response 2

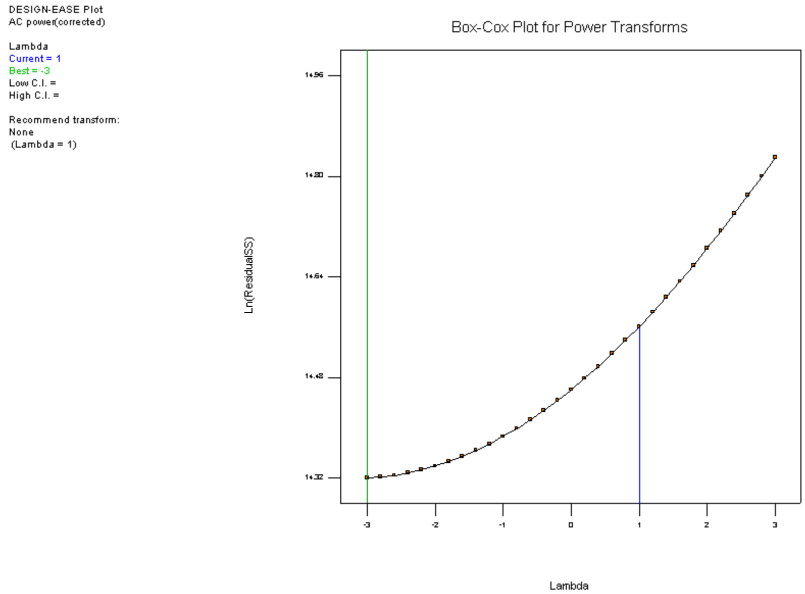


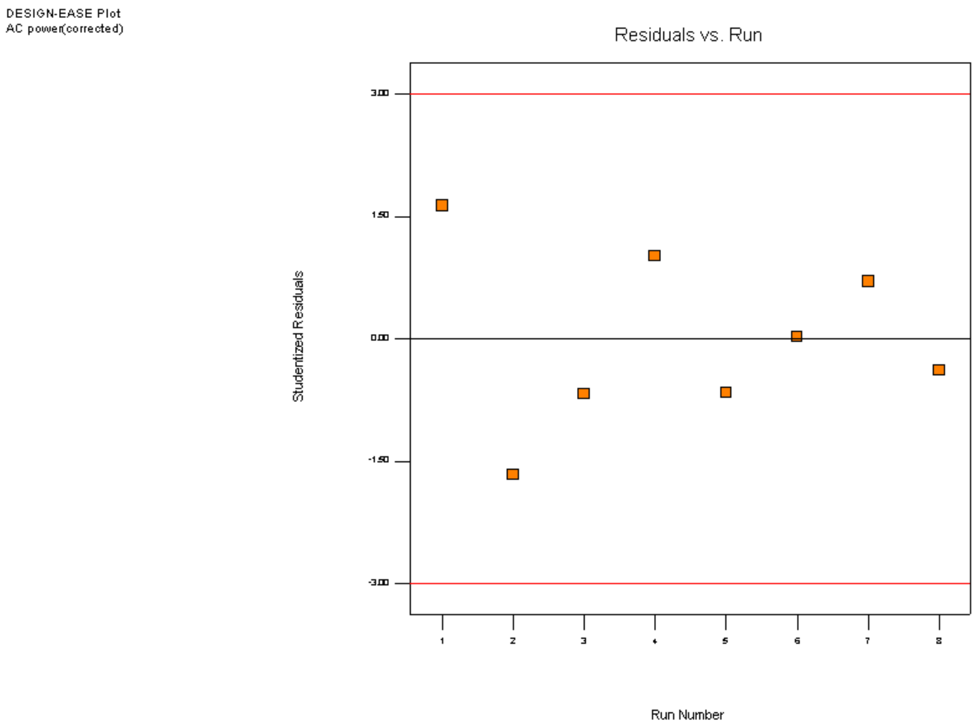
DESIGN-EASE Plot
delta in-out humid
Residuals vs. Run
Studentized Residuals
3.00
1.50
0.00
-1.50
-3.00
1
2
3
4
5
6
7
8
Run Number


DESIGN-EASE Plot
water into bldg
A: inside temp
B: desiccant regen temp
C: outside air flow
Half Normal plot
Half Normal % probability
|Effect|
C


DESIGN-EASE Plot
water into bldg
Residuals vs. Run
Studentized Residuals
Run Number

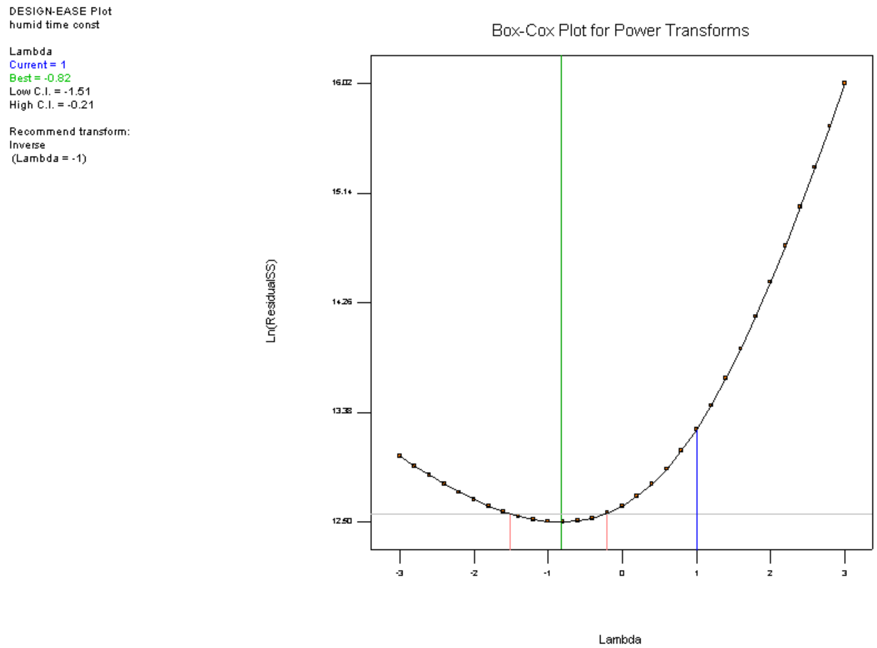
Response 4

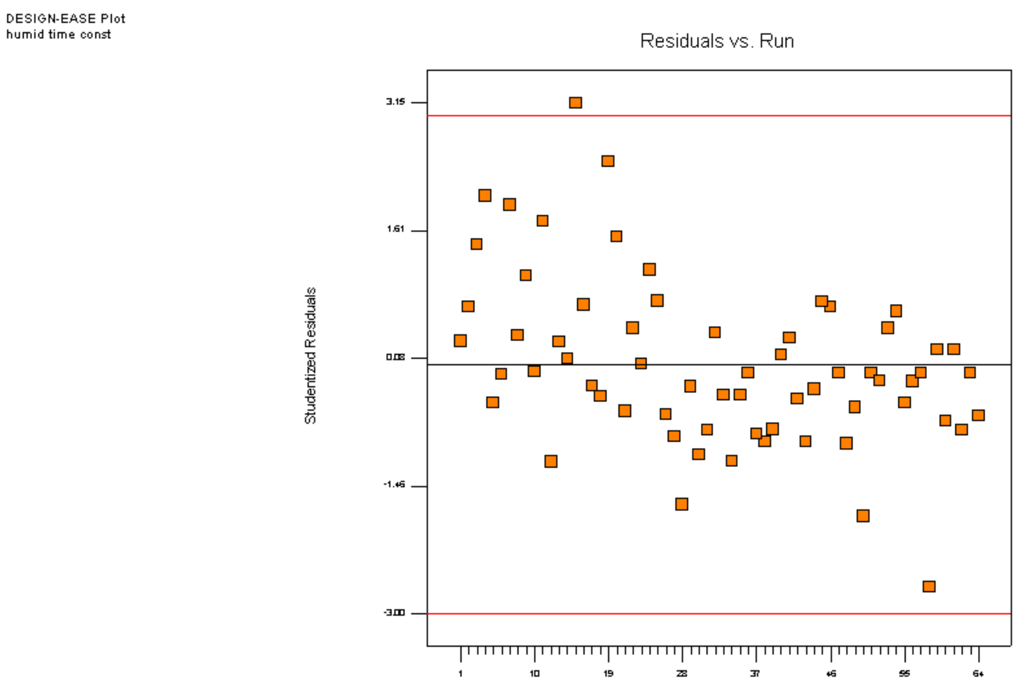

DESIGN-EASE Plot
AC power(corrected)
Lambda
Current = 1
Best = -3
Low C.I. =
High C.I. =
Recommend transform:
None
(Lambda = 1)
Box-Cox Plot for Power Transforms
14.96
14.80
14.64
14.48
14.32
Ln(ResidualSS)
-3
-2
-1
0
1
2
3
Lambda


DESIGN-EASE Plot
AC power(corrected)
Residuals vs. Run
3.00
1.50
0.00
-1.50
-3.00
Studentized Residuals
1
2
3
4
5
6
7
8
Run Number

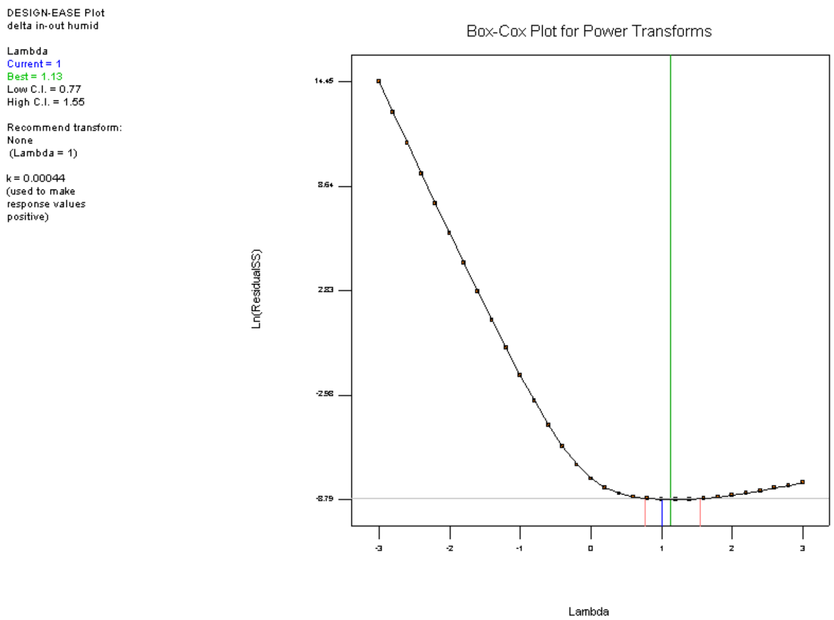
Appendix F. Additional Analytic Results for Task 6 Case 4

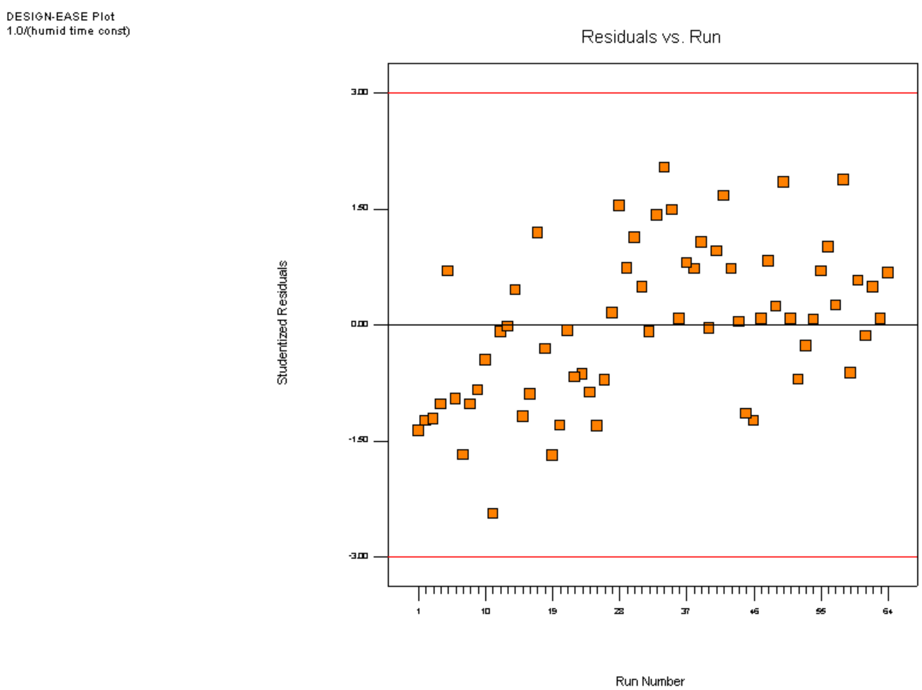
Response 1 (Humidity Time Constant)





Response 2 (Delta In-Out Humidity)



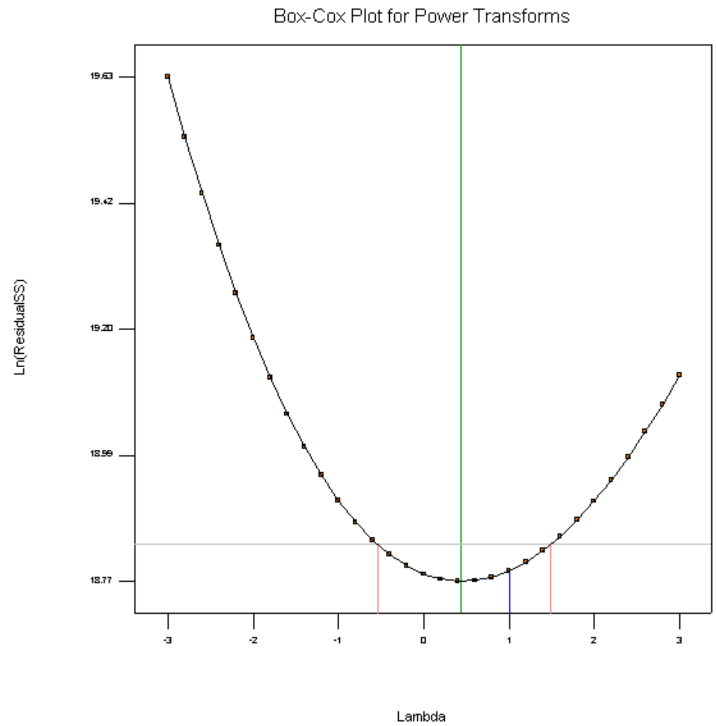


Response 3 (A/C Power)

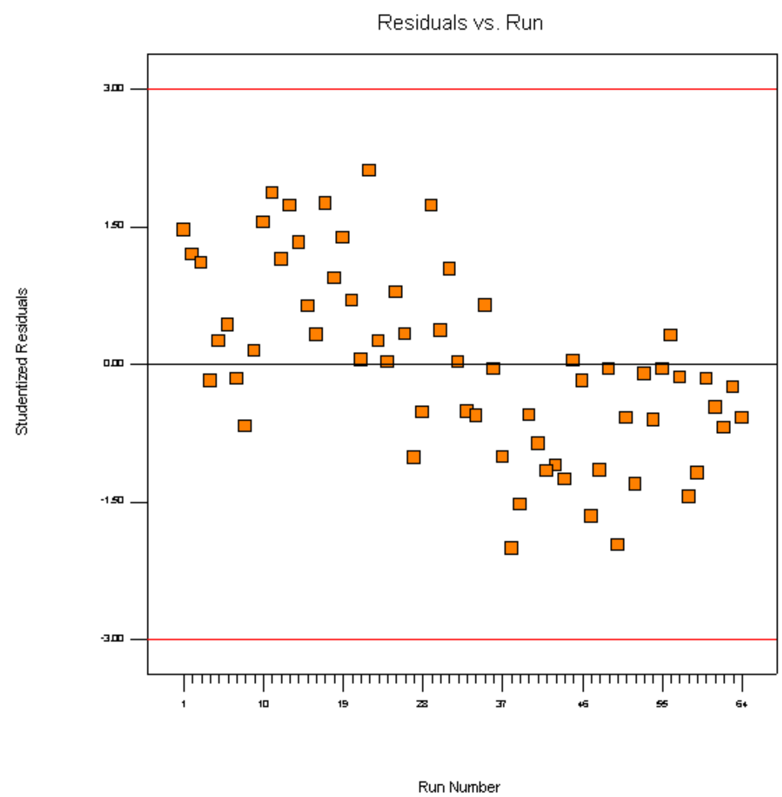
DESIGN-EASE Plot
AC power

Lambda
Current = 1
Best = 0.44
Low C.I. = -0.54
High C.I. = 1.49

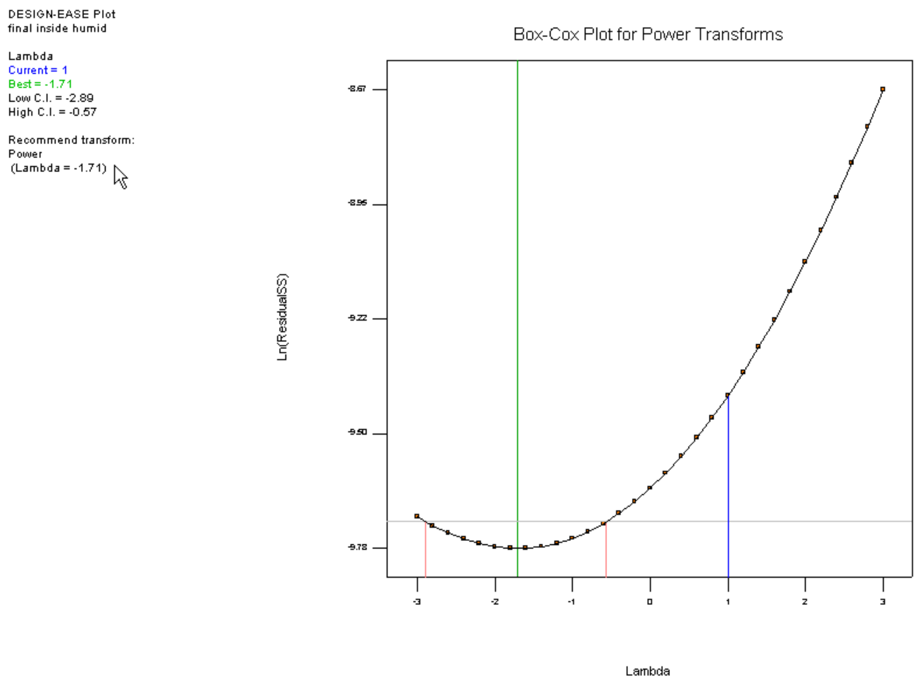
Recommend transform:
None
(Lambda = 1)

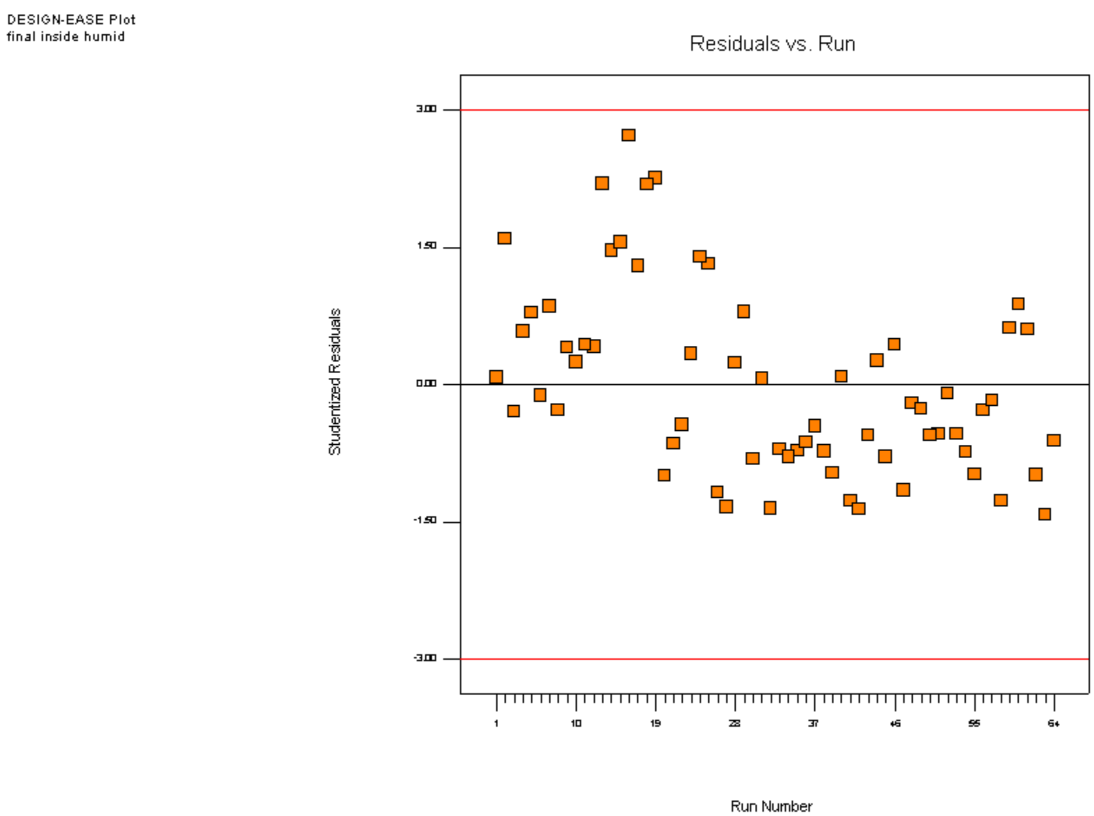


DESIGN-EASE Plot
AC power

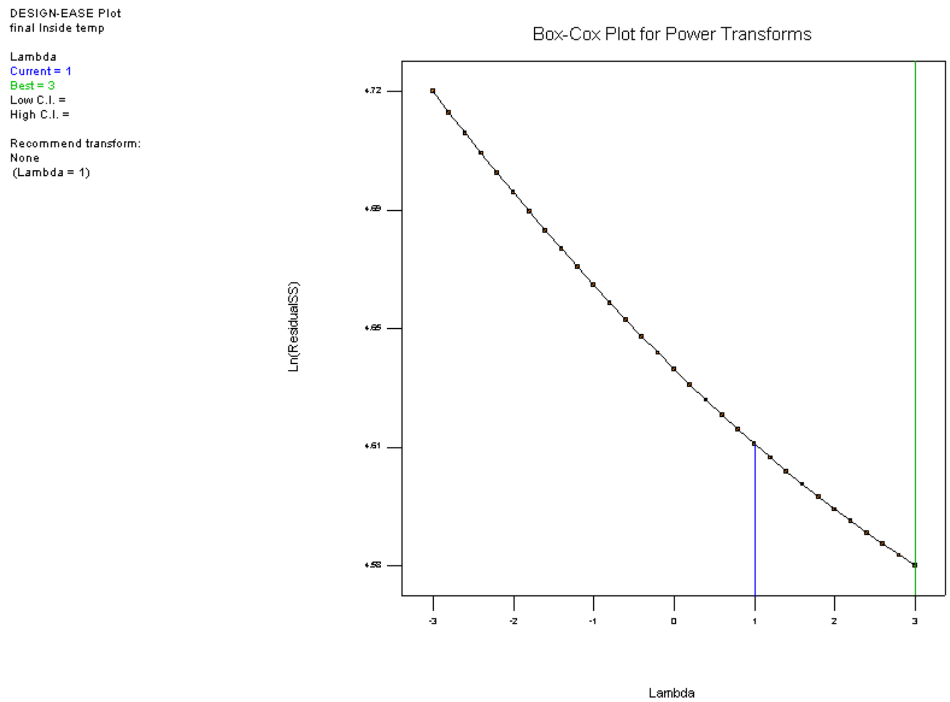


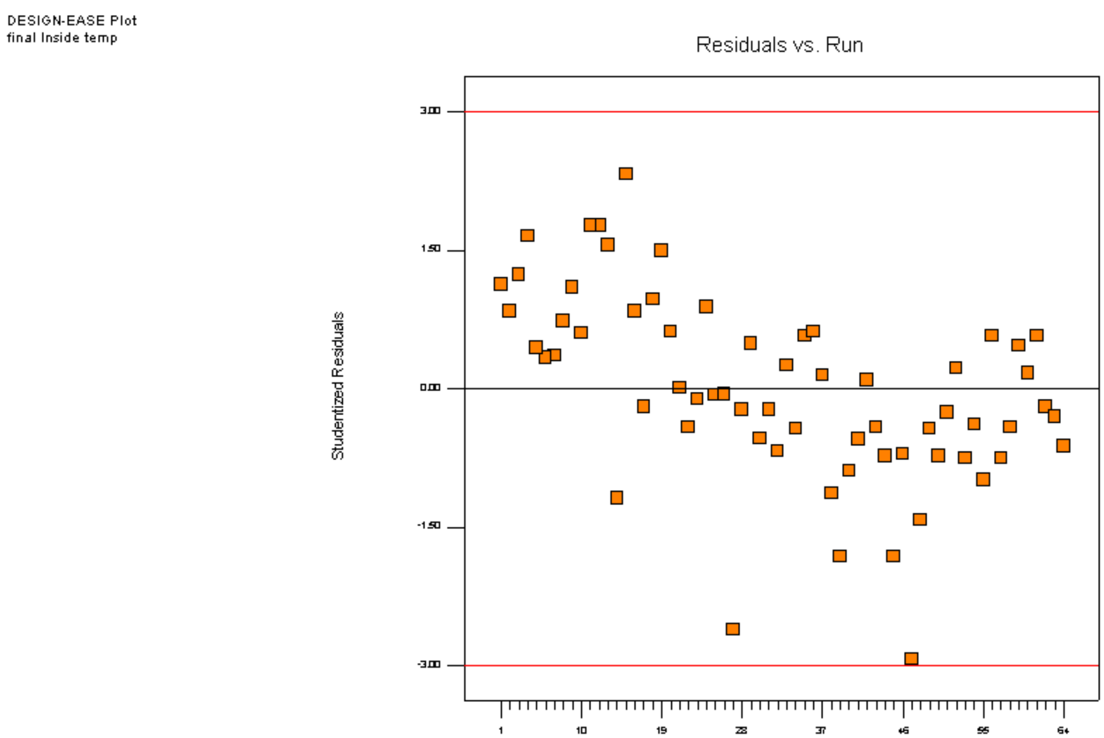
Response 4 (Final Inside Humidity)





Response 7 (Final Inside Temperature)





Appendix G. Warehouse Data

Table G-1. Warehouse Heating Data (Single Zone)

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
0:00:00	125.0	139.9	105258	12540	92718	54.2	78.7	84.6	32.4
0:01:00	124.7	139.6	105329	12027	93302	54.2	78.5	84.6	32.4
0:02:00	124.7	139.6	104820	11730	93090	54.3	78.2	84.6	32.3
0:03:00	124.5	139.6	106404	11596	94807	54.5	78.1	84.6	32.3
0:04:00	124.6	139.5	105244	11346	93898	54.5	77.6	84.6	32.2
0:05:00	124.5	139.6	106651	11823	94828	54.4	76.9	84.6	32.2
0:06:00	124.6	139.7	106941	12027	94914	54.3	76.6	84.6	32.2
0:07:00	124.6	140.0	108623	12397	96227	54.4	76.4	84.7	32.2
0:08:00	124.8	140.3	109670	12832	96838	54.4	76.3	84.7	32.2
0:09:00	124.9	140.2	108348	12678	95670	54.4	76.2	84.6	32.2
0:10:00	125.0	140.2	108023	12510	95512	54.5	76.0	84.6	32.2
0:11:00	125.0	140.4	109083	12908	96175	54.4	75.8	84.6	32.2
0:12:00	125.1	140.4	107973	13321	94652	54.1	75.3	84.5	32.2
0:13:00	125.2	140.4	107605	13497	94108	54.1	75.3	84.5	32.1
0:14:00	125.2	140.4	107676	13840	93836	53.9	75.1	84.5	32.1
0:15:00	125.1	140.5	108843	14007	94836	53.9	75.1	84.5	32.1
0:16:00	125.2	140.5	108553	14097	94456	53.8	75.1	84.6	32.1
0:17:00	125.2	140.1	105986	13741	92245	53.6	75.1	84.6	32.1
0:18:00	125.0	139.7	103696	13258	90438	53.5	75.1	84.6	32.1
0:19:00	124.7	139.4	104099	13150	90948	53.3	74.9	84.6	32.1
0:20:00	124.4	139.3	105046	12989	92057	53.2	75.1	84.6	32.1
0:21:00	124.2	139.1	105421	12513	92908	53.4	75.6	84.6	32.1
0:22:00	124.4	139.6	107874	12981	94893	53.6	76.0	84.6	32.0
0:23:00	124.5	139.7	107344	12829	94515	53.8	76.3	84.6	32.0
0:24:00	124.6	139.8	107535	12832	94703	53.9	76.3	84.5	32.0
0:25:00	124.7	140.1	109189	13146	96043	54.0	76.3	84.5	32.0
0:26:00	124.8	140.1	108058	13354	94704	53.8	75.7	84.5	32.0
0:27:00	124.9	140.0	106821	13509	93311	53.7	75.2	84.5	32.1
0:28:00	124.8	140.2	108532	14235	94296	53.4	74.8	84.5	32.0
0:29:00	125.0	140.2	107436	14605	92831	53.2	74.7	84.4	32.0
0:30:00	124.8	140.2	109090	14897	94193	53.0	74.7	84.5	32.1
0:31:00	124.9	140.3	108779	15157	93622	52.9	75.1	84.5	32.0
0:32:00	125.0	140.3	107931	15365	92566	52.8	75.3	84.5	32.0
0:33:00	125.2	140.1	105583	15174	90410	52.7	75.5	84.5	32.0
0:34:00	125.1	140.3	107584	15607	91977	52.6	75.5	84.5	32.0
0:35:00	124.9	140.1	107047	15283	91764	52.6	75.9	84.5	31.9
0:36:00	125.0	140.1	107075	15502	91573	52.5	76.0	84.5	31.9

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
0:37:00	125.0	140.2	107690	15691	91999	52.4	76.2	84.5	31.9
0:38:00	124.8	140.1	108383	15842	92541	52.3	76.3	84.5	31.8
0:39:00	124.9	140.1	107478	15869	91610	52.2	76.4	84.5	31.8
0:40:00	124.9	140.0	106637	15791	90846	52.2	76.7	84.5	31.8
0:41:00	124.9	139.8	105385	15705	89680	52.1	76.7	84.5	31.8
0:42:00	124.8	140.0	107422	16181	91241	52.0	76.8	84.5	31.8
0:43:00	124.8	140.1	108023	16319	91703	52.0	77.0	84.5	31.7
0:44:00	124.8	140.0	107195	16210	90985	51.9	77.1	84.5	31.7
0:45:00	124.8	140.0	107938	16290	91648	51.9	77.4	84.5	31.7
0:46:00	125.0	140.1	106842	16428	90414	51.9	77.4	84.5	31.7
0:47:00	124.8	140.1	108348	16610	91738	51.7	77.4	84.5	31.7
0:48:00	124.9	140.1	107209	16641	90569	51.7	77.5	84.5	31.7
0:49:00	124.8	140.0	107464	16400	91064	51.8	78.1	84.5	31.7
0:50:00	124.9	140.0	107089	16324	90765	51.9	78.4	84.4	31.7
0:51:00	124.9	140.0	106524	16136	90388	51.9	78.6	84.4	31.7
0:52:00	124.8	140.1	108341	16066	92275	52.1	78.9	84.4	31.7
0:53:00	124.9	139.9	106213	15331	90882	52.4	79.4	84.4	31.7
0:54:00	124.7	140.1	108998	15632	93366	52.4	78.9	84.4	31.7
0:55:00	124.9	140.1	107627	15399	92227	52.5	78.9	84.4	31.7
0:56:00	124.8	140.0	107556	15042	92514	52.7	79.0	84.4	31.7
0:57:00	124.9	140.0	106587	14886	91701	52.8	79.0	84.4	31.7
0:58:00	125.0	139.9	105711	14400	91311	53.0	79.1	84.4	31.7
0:59:00	124.8	140.0	107379	14060	93320	53.3	79.1	84.4	31.7
1:00:00	124.8	140.0	108001	13873	94128	53.5	79.0	84.4	31.7
1:01:00	124.7	139.9	107662	13791	93871	53.4	78.5	84.4	31.7
1:02:00	124.8	139.9	106757	14223	92534	53.1	77.6	84.4	31.7
1:03:00	124.7	139.8	106757	14161	92596	53.1	77.3	84.4	31.6
1:04:00	124.7	139.8	107209	14599	92611	52.8	76.7	84.4	31.6
1:05:00	124.6	139.9	108058	15042	93016	52.6	76.3	84.4	31.5
1:06:00	124.7	139.8	106891	15062	91829	52.5	76.3	84.4	31.4
1:07:00	124.7	139.7	106333	15092	91241	52.4	76.1	84.4	31.4
1:08:00	124.6	139.8	107167	15105	92062	52.4	76.5	84.4	31.4
1:09:00	124.6	139.8	107280	15449	91831	52.2	76.5	84.4	31.3
1:10:00	124.6	139.9	108164	16078	92086	51.9	76.3	84.4	31.4
1:11:00	124.6	139.8	106877	16117	90760	51.7	76.3	84.4	31.4
1:12:00	124.6	139.9	107938	16388	91550	51.7	76.5	84.4	31.3
1:13:00	124.6	139.7	107259	16341	90918	51.6	76.6	84.4	31.3
1:14:00	124.7	139.8	107082	16524	90558	51.5	77.0	84.4	31.3
1:15:00	124.6	139.8	107407	16551	90857	51.5	77.4	84.4	31.3
1:16:00	124.5	139.7	107153	16535	90618	51.4	77.4	84.4	31.3
1:17:00	124.6	139.7	106764	16405	90359	51.5	77.7	84.4	31.3

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
1:18:00	124.6	139.7	107174	16019	91155	51.8	78.7	84.3	31.3
1:19:00	124.5	139.9	108560	15907	92652	52.0	79.1	84.3	31.3
1:20:00	124.7	140.4	110638	16711	93928	52.0	79.0	84.4	31.3
1:21:00	125.0	140.4	109401	16666	92735	52.0	78.9	84.4	31.3
1:22:00	125.1	140.7	110080	17054	93026	52.0	78.7	84.3	31.3
1:23:00	125.1	140.8	111091	16958	94133	52.2	79.0	84.4	31.3
1:24:00	125.2	140.6	109076	16540	92536	52.3	79.0	84.4	31.3
1:25:00	125.1	140.3	107627	16105	91522	52.3	79.0	84.4	31.3
1:26:00	125.0	140.0	106616	15870	90745	52.2	78.4	84.4	31.3
1:27:00	124.8	139.9	106665	15806	90859	52.1	78.1	84.4	31.2
1:28:00	124.8	139.8	106481	16102	90380	51.8	77.5	84.4	31.3
1:29:00	124.7	139.7	106099	16027	90072	51.7	77.4	84.4	31.2
1:30:00	124.5	139.7	107535	15681	91854	51.9	77.9	84.4	31.2
1:31:00	124.6	139.6	106135	15082	91053	52.2	78.7	84.4	31.2
1:32:00	124.5	139.5	105838	14743	91095	52.4	78.9	84.4	31.2
1:33:00	124.6	139.6	105958	14992	90966	52.3	78.4	84.3	31.2
1:34:00	124.5	139.5	106453	14944	91509	52.3	78.2	84.3	31.2
1:35:00	124.4	139.4	105725	15012	90713	52.1	77.7	84.3	31.2
1:36:00	124.2	139.7	109634	15581	94053	52.0	77.3	84.3	31.2
1:37:00	124.5	140.0	109903	16038	93865	52.1	77.5	84.3	31.2
1:38:00	124.8	140.3	109825	16319	93506	52.1	77.8	84.3	31.2
1:39:00	124.8	140.5	110624	16259	94366	52.4	78.1	84.3	31.2
1:40:00	125.1	140.5	109422	16214	93209	52.5	78.0	84.3	31.1
1:41:00	125.1	140.8	110497	16641	93856	52.4	77.5	84.3	31.2
1:42:00	125.1	140.5	108701	16744	91958	52.0	76.7	84.3	31.1
1:43:00	125.1	140.2	106715	16625	90089	51.8	76.3	84.3	31.0
1:44:00	125.0	140.1	107118	16678	90439	51.7	76.4	84.3	31.0
1:45:00	124.9	140.0	107082	16680	90402	51.7	76.7	84.3	30.9
1:46:00	124.8	140.0	107118	16754	90363	51.5	76.7	84.3	31.0
1:47:00	124.7	140.0	108235	16863	91371	51.5	76.8	84.3	30.9
1:48:00	124.7	139.7	105725	16627	89098	51.3	77.0	84.3	30.9
1:49:00	124.6	139.8	106962	17115	89847	51.1	77.1	84.3	30.9
1:50:00	124.7	139.7	106227	17200	89026	51.0	77.2	84.3	30.9
1:51:00	124.5	139.5	105958	17110	88848	50.8	77.4	84.2	30.9
1:52:00	124.4	139.5	106198	17247	88951	50.7	77.5	84.2	30.9
1:53:00	124.5	139.4	104862	17015	87847	50.8	77.8	84.2	30.8
1:54:00	124.3	139.6	108496	17070	91426	51.0	78.6	84.3	30.9
1:55:00	124.5	140.3	112052	17667	94386	51.3	79.4	84.3	30.9
1:56:00	124.8	140.5	110865	17819	93046	51.4	79.4	84.2	30.9
1:57:00	125.0	140.7	110978	18007	92971	51.5	79.4	84.2	30.9
1:58:00	125.2	140.3	107139	17595	89544	51.4	79.0	84.3	30.9

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
1:59:00	125.1	140.3	107400	17724	89676	51.2	78.2	84.3	30.8
2:00:00	125.0	140.1	106884	17761	89123	51.1	77.8	84.2	30.8
2:01:00	125.0	140.1	107096	17858	89239	51.0	77.8	84.2	30.8
2:02:00	125.0	140.1	106234	17660	88573	51.0	78.0	84.2	30.8
2:03:00	124.8	140.0	107153	17402	89750	51.1	78.2	84.2	30.8
2:04:00	124.8	140.0	107301	17339	89963	51.2	78.2	84.2	30.8
2:05:00	124.8	140.0	107860	17003	90857	51.4	78.3	84.2	30.8
2:06:00	124.8	139.9	106708	16462	90245	51.6	78.4	84.2	30.8
2:07:00	124.7	139.9	107323	16492	90831	51.6	78.1	84.2	30.8
2:08:00	124.6	139.8	107450	16585	90865	51.5	77.5	84.2	30.8
2:09:00	124.6	139.8	107217	16754	90462	51.3	77.1	84.2	30.8
2:10:00	124.7	139.6	105633	16235	89398	51.5	77.4	84.2	30.8
2:11:00	124.7	139.8	107195	16371	90825	51.6	77.6	84.2	30.8
2:12:00	124.6	139.8	107492	16224	91268	51.7	77.5	84.2	30.7
2:13:00	124.7	139.9	108023	16851	91172	51.4	76.7	84.2	30.7
2:14:00	124.5	139.9	108411	16908	91503	51.3	76.3	84.2	30.7
2:15:00	124.6	140.0	109019	17460	91559	51.1	76.1	84.2	30.6
2:16:00	124.6	139.9	108447	17432	91015	51.1	76.3	84.2	30.6
2:17:00	124.7	139.9	107825	17168	90657	51.2	77.1	84.2	30.5
2:18:00	124.7	139.8	107231	17000	90231	51.2	77.4	84.2	30.5
2:19:00	124.5	139.9	108963	17182	91781	51.2	77.4	84.2	30.5
2:20:00	124.6	139.9	107683	17001	90682	51.3	77.4	84.2	30.5
2:21:00	124.5	139.8	107591	16950	90641	51.2	77.2	84.2	30.5
2:22:00	124.6	139.6	105838	16759	89079	51.1	77.0	84.2	30.5
2:23:00	124.6	139.8	108001	17162	90840	51.1	76.9	84.2	30.5
2:24:00	124.6	140.4	111791	18148	93642	51.0	76.7	84.2	30.5
2:25:00	124.9	140.8	111953	19124	92829	50.8	76.4	84.2	30.5
2:26:00	125.1	140.7	110539	19281	91258	50.7	76.3	84.2	30.5
2:27:00	125.2	140.4	107351	18641	88710	50.7	76.7	84.2	30.5
2:28:00	125.0	140.4	108836	18399	90437	50.9	77.3	84.2	30.5
2:29:00	125.0	140.3	108447	18122	90325	51.0	77.6	84.2	30.5
2:30:00	124.9	140.2	108263	17765	90498	51.1	77.8	84.2	30.5
2:31:00	124.7	140.0	108143	17480	90663	51.1	77.8	84.2	30.4
2:32:00	124.8	140.2	108680	17922	90759	51.0	77.7	84.2	30.4
2:33:00	124.7	140.1	109012	17976	91036	50.9	77.4	84.2	30.4
2:34:00	124.9	140.0	106934	17873	89060	50.8	77.4	84.2	30.4
2:35:00	124.7	140.0	108623	17800	90823	50.9	77.6	84.2	30.4
2:36:00	124.7	140.0	108348	18033	90314	50.8	77.5	84.2	30.4
2:37:00	124.7	140.0	108539	18179	90359	50.7	77.4	84.2	30.4
2:38:00	124.6	139.9	108157	17979	90178	50.7	77.6	84.2	30.4
2:39:00	124.6	139.9	108602	18193	90409	50.6	77.5	84.2	30.4

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
2:40:00	124.6	139.7	106806	18027	88779	50.5	77.5	84.2	30.3
2:41:00	124.5	139.8	107641	18439	89202	50.2	77.5	84.2	30.3
2:42:00	124.5	139.7	107627	18593	89034	50.1	77.5	84.2	30.3
2:43:00	124.5	139.6	106552	18582	87970	49.9	77.8	84.2	30.3
2:44:00	124.4	139.6	107485	18823	88662	49.8	77.9	84.2	30.2
2:45:00	124.3	139.5	107280	18727	88554	49.8	78.2	84.1	30.2
2:46:00	124.3	139.5	107471	18765	88706	49.7	78.6	84.1	30.2
2:47:00	124.2	139.4	107655	18817	88838	49.7	78.6	84.1	30.2
2:48:00	124.2	139.7	109578	19421	90157	49.6	78.6	84.1	30.2
2:49:00	124.4	140.0	110419	19884	90535	49.6	78.9	84.1	30.1
2:50:00	124.6	140.4	111883	20560	91322	49.5	79.0	84.1	30.1
2:51:00	124.8	140.4	110518	20731	89787	49.4	79.0	84.1	30.1
2:52:00	124.9	140.8	111939	21247	90692	49.4	79.1	84.1	30.1
2:53:00	125.0	140.7	111041	21162	89880	49.5	79.4	84.1	30.2
2:54:00	125.0	140.5	109663	20627	89036	49.6	79.5	84.1	30.1
2:55:00	125.0	140.3	107825	20105	87720	49.7	79.6	84.1	30.1
2:56:00	125.0	140.2	107103	19393	87710	50.0	80.0	84.1	30.1
2:57:00	124.7	140.0	107931	18840	89091	50.2	80.2	84.1	30.1
2:58:00	124.7	139.9	106955	18462	88493	50.3	80.2	84.1	30.1
2:59:00	124.5	139.9	108270	18332	89938	50.4	79.9	84.1	30.1
3:00:00	124.7	139.9	107648	18509	89139	50.3	79.5	84.1	30.1
3:01:00	124.7	139.8	107202	18343	88860	50.4	79.2	84.1	30.1
3:02:00	124.6	139.8	107535	17984	89551	50.6	79.4	84.1	30.1
3:03:00	124.6	139.8	107697	17718	89979	50.8	79.3	84.1	30.0
3:04:00	124.5	139.6	106898	17303	89595	50.8	78.6	84.1	30.0
3:05:00	124.4	139.7	108192	17301	90891	51.0	78.3	84.1	30.0
3:06:00	124.4	139.6	107075	17244	89831	50.8	77.9	84.0	30.0
3:07:00	124.3	139.7	108567	17876	90690	50.5	77.1	84.0	30.0
3:08:00	124.3	139.6	107973	18068	89905	50.3	76.8	84.0	30.0
3:09:00	124.4	139.5	106920	18366	88554	50.0	76.7	84.0	30.0
3:10:00	124.5	139.9	109140	19165	89975	50.0	76.7	84.0	30.0
3:11:00	124.5	140.3	111048	19912	91136	49.8	77.0	84.0	30.0
3:12:00	124.6	140.5	112406	20452	91954	49.7	77.3	84.0	30.0
3:13:00	124.9	140.5	110200	20646	89554	49.6	77.4	84.1	30.0
3:14:00	125.0	140.7	111261	21160	90100	49.4	77.5	84.1	30.0
3:15:00	125.0	140.8	111713	21501	90212	49.3	77.8	84.0	30.0
3:16:00	125.0	140.5	109224	21112	88112	49.2	77.9	84.0	29.9
3:17:00	125.0	140.1	107061	20663	86398	49.2	78.2	84.0	29.9
3:18:00	124.8	139.9	107054	20374	86680	49.1	78.4	84.0	29.8
3:19:00	124.7	139.8	106700	20166	86535	49.1	78.6	84.0	29.8
3:20:00	124.5	139.7	107726	19919	87807	49.3	79.1	84.0	29.7

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
3:21:00	124.4	139.7	108185	19732	88453	49.4	79.4	84.0	29.7
3:22:00	124.4	139.6	107754	19479	88275	49.4	79.4	84.0	29.7
3:23:00	124.4	139.5	107047	19309	87738	49.4	79.4	83.9	29.7
3:24:00	124.3	139.4	106806	18978	87828	49.5	79.4	83.9	29.7
3:25:00	124.2	139.4	107740	19204	88536	49.4	79.4	84.0	29.7
3:26:00	124.3	139.4	107075	19350	87725	49.3	79.1	83.9	29.7
3:27:00	124.3	139.6	108525	19799	88726	49.2	78.8	84.0	29.7
3:28:00	124.4	139.7	108220	20086	88134	49.1	78.9	84.0	29.7
3:29:00	124.5	139.9	108956	20389	88566	49.1	79.0	83.9	29.7
3:30:00	124.4	139.9	109536	20407	89129	49.1	79.0	84.0	29.7
3:31:00	124.5	139.9	108793	20192	88601	49.2	79.0	83.9	29.7
3:32:00	124.6	140.1	109790	20189	89601	49.5	79.3	84.0	29.7
3:33:00	124.6	140.2	109868	20135	89733	49.5	79.4	83.9	29.7
3:34:00	124.6	140.1	109069	19925	89144	49.6	79.2	84.0	29.6
3:35:00	124.6	140.1	109168	20222	88946	49.4	78.8	84.0	29.6
3:36:00	124.7	140.1	108991	20587	88404	49.2	78.3	83.9	29.6
3:37:00	124.6	140.2	110250	20972	89277	49.1	78.3	84.0	29.7
3:38:00	124.6	140.0	109217	20874	88343	48.9	78.2	84.0	29.6
3:39:00	124.6	140.0	108913	21027	87887	48.9	78.4	83.9	29.7
3:40:00	124.6	139.9	108242	20927	87315	48.8	78.7	83.9	29.6
3:41:00	124.5	140.1	110313	21311	89002	48.8	78.7	83.9	29.6
3:42:00	124.5	140.0	109627	21216	88411	48.7	78.8	84.0	29.6
3:43:00	124.5	140.0	110165	21336	88829	48.7	78.9	84.0	29.6
3:44:00	124.6	139.9	108489	21086	87403	48.7	79.1	83.9	29.6
3:45:00	124.5	139.9	109069	21019	88050	48.7	79.4	83.9	29.6
3:46:00	124.5	140.0	109168	20991	88177	48.8	79.4	83.9	29.7
3:47:00	124.5	140.1	109953	21039	88914	48.9	79.4	83.9	29.6
3:48:00	124.7	140.0	108206	20598	87609	49.1	79.6	83.9	29.6
3:49:00	124.6	139.9	108114	20065	88050	49.4	79.8	83.9	29.5
3:50:00	124.6	140.1	109458	20069	89388	49.5	80.2	83.9	29.5
3:51:00	124.7	140.1	108609	20010	88599	49.5	80.0	83.9	29.5
3:52:00	124.7	140.0	108008	19665	88343	49.7	79.8	83.9	29.5
3:53:00	124.7	140.1	108906	19480	89426	49.9	79.8	83.9	29.4
3:54:00	124.8	140.2	108998	19344	89655	50.1	79.8	83.9	29.4
3:55:00	124.7	140.2	109352	19177	90174	50.2	79.5	83.9	29.4
3:56:00	124.7	140.2	109889	19070	90819	50.3	79.0	83.9	29.4
3:57:00	124.7	140.3	109663	18918	90745	50.4	78.4	83.9	29.4
3:58:00	124.7	140.2	109536	18838	90697	50.4	77.9	83.9	29.4
3:59:00	124.6	140.2	110440	19005	91436	50.4	77.5	83.9	29.3
4:00:00	124.7	140.3	109953	18924	91029	50.5	77.4	83.9	29.3
4:01:00	124.8	140.2	108666	18523	90143	50.6	77.4	83.9	29.3

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
4:02:00	124.8	140.2	109465	18812	90653	50.5	77.0	84.0	29.3
4:03:00	124.7	140.2	109762	18796	90965	50.5	76.8	84.0	29.3
4:04:00	124.8	140.3	109748	19423	90325	50.2	76.2	84.0	29.3
4:05:00	124.8	140.2	108737	19239	89497	50.2	76.1	84.0	29.3
4:06:00	124.8	140.1	108228	18949	89279	50.2	76.3	83.9	29.3
4:07:00	124.6	139.9	108100	18901	89200	50.1	76.1	84.0	29.3
4:08:00	124.6	139.8	107902	18899	89003	50.0	75.9	84.0	29.3
4:09:00	124.6	139.7	106997	18672	88325	50.0	75.7	83.9	29.3
4:10:00	124.3	139.6	107931	18514	89417	50.0	75.9	84.0	29.3
4:11:00	124.4	139.6	107825	18573	89252	50.0	75.9	83.9	29.3
4:12:00	124.4	139.5	107068	18344	88724	50.0	76.3	83.9	29.3
4:13:00	124.2	139.5	108008	18332	89677	50.1	76.4	83.9	29.3
4:14:00	124.2	139.4	107464	18307	89157	50.0	76.3	83.9	29.3
4:15:00	124.1	139.8	111077	19036	92041	49.9	76.3	83.9	29.2
4:16:00	124.4	140.1	111275	19528	91746	49.9	76.5	83.9	29.2
4:17:00	124.5	140.1	110207	19693	90514	49.8	76.5	83.9	29.2
4:18:00	124.7	140.1	109083	19597	89486	49.9	76.6	83.9	29.2
4:19:00	124.8	140.3	109677	19690	89987	50.0	76.9	83.9	29.2
4:20:00	124.8	140.6	111565	19675	91890	50.3	77.2	83.9	29.3
4:21:00	125.0	140.4	109026	18924	90103	50.6	77.5	83.9	29.2
4:22:00	125.1	140.7	109733	19098	90635	50.7	77.2	83.9	29.2
4:23:00	125.1	140.4	108298	18565	89733	50.8	76.7	83.9	29.2
4:24:00	124.9	140.2	108228	18383	89844	50.7	76.2	83.9	29.1
4:25:00	124.8	140.1	108171	18413	89758	50.6	75.3	83.9	29.2
4:26:00	124.8	139.9	107075	17796	89280	50.8	75.2	83.9	29.0
4:27:00	124.7	139.9	107711	17581	90130	50.9	75.1	84.0	29.0
4:28:00	124.4	139.8	108503	17157	91346	51.1	75.1	84.0	29.0
4:29:00	124.6	139.7	107061	16942	90119	51.2	74.9	84.0	28.9
4:30:00	124.5	139.9	108779	17227	91552	51.1	74.3	84.0	28.9
4:31:00	124.4	139.9	109840	17309	92530	51.1	73.9	84.0	28.9
4:32:00	124.3	139.7	109196	17039	92157	51.1	73.3	84.0	28.9
4:33:00	124.6	139.8	107259	16963	90296	51.2	73.1	84.0	28.9
4:34:00	124.6	139.8	107846	16666	91180	51.4	72.9	84.0	28.9
4:35:00	124.5	139.8	108383	16489	91894	51.5	72.4	84.0	28.9
4:36:00	124.5	139.7	107662	16240	91422	51.6	71.6	84.0	28.9
4:37:00	124.4	139.7	108220	16201	92019	51.6	71.2	84.0	28.9
4:38:00	124.4	139.8	108496	16352	92144	51.6	70.9	84.0	28.9
4:39:00	124.4	139.7	107825	16210	91614	51.6	70.7	84.0	28.9
4:40:00	124.5	140.1	110426	17312	93114	51.4	70.2	84.0	28.9
4:41:00	124.7	140.2	110087	17772	92315	51.1	70.0	84.0	28.9
4:42:00	124.9	140.7	111593	18504	93089	51.1	70.2	84.0	28.8

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
4:43:00	125.0	140.8	112010	18776	93234	51.1	70.4	84.0	28.9
4:44:00	125.1	140.7	110539	18709	91830	51.0	70.5	84.0	28.9
4:45:00	125.3	140.6	108157	18577	89580	51.0	70.5	84.0	28.8
4:46:00	125.1	140.3	107556	18254	89302	50.9	70.4	84.0	28.8
4:47:00	124.8	140.0	107535	17844	89691	50.9	70.7	84.0	28.8
4:48:00	124.7	140.0	107662	17732	89930	50.9	71.0	84.0	28.8
4:49:00	124.7	139.9	108037	17898	90138	50.8	70.8	84.0	28.7
4:50:00	124.7	140.0	107888	17998	89891	50.8	71.1	84.1	28.7
4:51:00	124.6	140.0	108659	18253	90406	50.6	71.1	84.1	28.7
4:52:00	124.6	139.9	108355	18193	90161	50.6	71.2	84.1	28.6
4:53:00	124.6	140.0	108892	18305	90587	50.5	71.5	84.0	28.6
4:54:00	124.6	140.0	108899	18223	90676	50.6	71.9	84.0	28.6
4:55:00	124.5	139.8	108433	18052	90381	50.5	72.0	84.0	28.6
4:56:00	124.6	139.7	107195	18273	88923	50.3	71.9	84.0	28.6
4:57:00	124.5	139.8	107980	18400	89580	50.3	72.4	83.9	28.6
4:58:00	124.5	139.6	106750	18332	88418	50.1	72.7	84.0	28.6
4:59:00	124.4	139.6	107415	18420	88994	50.1	72.8	84.0	28.6
5:00:00	124.3	139.6	108334	18350	89983	50.2	73.2	83.9	28.6
5:01:00	124.3	139.6	108058	18179	89878	50.3	73.8	84.0	28.6
5:02:00	124.3	139.6	108319	18281	90039	50.2	73.9	83.9	28.6
5:03:00	124.3	139.7	108793	18270	90524	50.3	74.1	83.9	28.6
5:04:00	124.3	139.7	108730	18189	90541	50.3	74.3	83.9	28.6
5:05:00	124.4	139.9	109670	18360	91310	50.4	74.5	83.9	28.6
5:06:00	124.5	140.2	111126	18974	92153	50.4	74.6	83.9	28.6
5:07:00	124.7	140.5	111225	19651	91574	50.2	74.2	83.9	28.6
5:08:00	124.9	140.7	111261	19982	91278	50.1	74.2	83.9	28.6
5:09:00	125.1	140.7	110073	19942	90131	50.2	74.3	83.9	28.6
5:10:00	125.0	140.8	111225	19940	91285	50.3	74.4	83.9	28.6
5:11:00	125.1	140.2	107004	19126	87879	50.3	74.4	83.9	28.6
5:12:00	124.8	140.3	109196	19319	89877	50.2	74.3	83.9	28.6
5:13:00	124.9	140.1	107959	19096	88862	50.2	74.3	83.9	28.5
5:14:00	124.7	140.1	108864	19146	89718	50.1	74.3	83.9	28.5
5:15:00	124.7	139.9	107789	18925	88864	50.1	74.4	83.9	28.5
5:16:00	124.6	139.9	108136	18789	89347	50.1	74.4	84.0	28.5
5:17:00	124.6	139.8	107337	18518	88818	50.2	74.7	84.0	28.5
5:18:00	124.6	139.9	108079	18392	89687	50.4	74.8	84.0	28.5
5:19:00	124.6	139.8	107153	18545	88608	50.2	74.4	84.0	28.6
5:20:00	124.5	139.8	108037	18406	89630	50.3	74.3	83.9	28.5
5:21:00	124.4	139.9	109599	18225	91375	50.5	74.7	83.9	28.5
5:22:00	124.5	139.8	108376	17816	90560	50.7	74.7	83.9	28.5
5:23:00	124.5	139.8	107945	17646	90298	50.8	74.4	83.9	28.5

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
5:24:00	124.5	139.8	108426	17674	90751	50.8	74.1	83.9	28.5
5:25:00	124.5	139.8	107867	17514	90353	50.8	73.9	83.9	28.5
5:26:00	124.5	139.7	107782	17671	90111	50.7	73.4	83.9	28.5
5:27:00	124.5	139.7	107825	17929	89895	50.5	73.0	84.0	28.5
5:28:00	124.4	139.7	107987	18229	89758	50.3	72.7	83.9	28.5
5:29:00	124.3	139.6	108164	18899	89265	49.8	72.4	83.9	28.5
5:30:00	124.3	139.8	109613	19892	89721	49.4	72.4	83.9	28.5
5:31:00	124.5	140.1	110794	20809	89985	49.1	72.7	83.9	28.5
5:32:00	124.6	140.2	110462	21198	89264	48.9	73.2	83.9	28.4
5:33:00	124.8	140.5	110674	21801	88873	48.8	73.6	83.9	28.4
5:34:00	124.9	140.5	110928	22102	88826	48.7	74.0	83.9	28.3
5:35:00	124.9	140.5	110518	22085	88433	48.7	74.5	84.0	28.2
5:36:00	125.0	140.6	110158	21797	88360	48.9	75.2	84.0	28.2
5:37:00	125.0	140.3	108079	20848	87231	49.2	76.1	84.0	28.3
5:38:00	124.8	140.0	107513	19872	87642	49.6	76.6	84.0	28.2
5:39:00	124.6	140.0	108942	19344	89598	49.9	76.4	84.0	28.2
5:40:00	124.5	139.8	107853	18837	89016	50.0	75.7	83.9	28.2
5:41:00	124.6	139.7	107153	18434	88719	50.2	75.3	83.9	28.2
5:42:00	124.4	139.6	107386	17915	89471	50.4	75.1	83.9	28.2
5:43:00	124.4	139.6	107542	17625	89917	50.6	74.9	83.9	28.2
5:44:00	124.4	139.5	107061	17525	89536	50.6	74.5	83.9	28.2
5:45:00	124.3	139.7	109069	17684	91385	50.7	74.3	83.9	28.1
5:46:00	124.3	139.6	108426	17937	90488	50.4	73.6	83.9	28.1
5:47:00	124.3	139.8	109543	18551	90992	50.2	73.1	83.9	28.1
5:48:00	124.5	140.2	110935	19376	91559	50.1	73.0	83.9	28.1
5:49:00	124.6	140.3	111063	19844	91219	49.9	72.8	83.9	28.1
5:50:00	124.7	140.5	111847	19970	91878	50.0	73.2	83.9	28.1
5:51:00	124.8	140.5	110879	20127	90752	49.9	73.2	83.9	28.1
5:52:00	124.9	140.5	110129	20211	89919	49.8	73.3	83.9	28.1
5:53:00	124.8	140.1	108228	19558	88670	49.8	73.5	84.0	28.1
5:54:00	124.7	139.9	107521	19466	88054	49.7	73.5	83.9	28.1
5:55:00	124.5	139.7	106863	19166	87697	49.7	73.5	83.9	28.1
5:56:00	124.4	139.7	107916	19300	88616	49.6	73.5	83.9	28.1
5:57:00	124.3	139.5	107294	19067	88227	49.5	73.6	83.9	28.1
5:58:00	124.2	139.5	108220	19249	88972	49.4	73.7	83.9	28.1
5:59:00	124.3	139.8	109691	19665	90026	49.5	74.3	83.9	28.1
6:00:00	124.3	140.0	110575	19676	90899	49.7	74.4	83.9	28.1
6:01:00	124.6	140.1	109705	19818	89888	49.7	74.4	83.9	28.1
6:02:00	124.7	140.3	110207	19900	90307	49.8	74.3	83.9	28.1
6:03:00	124.6	140.4	111833	19858	91975	50.0	74.3	83.9	28.1
6:04:00	124.8	140.3	109578	19519	90059	50.1	74.0	83.9	28.1

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
6:05:00	124.9	140.3	109288	19449	89839	50.2	73.8	83.9	28.1
6:06:00	125.0	140.5	109521	19701	89820	50.1	73.5	83.9	28.1
6:07:00	125.0	140.5	109953	19689	90264	50.2	73.3	83.9	28.0
6:08:00	124.9	140.1	107386	18852	88534	50.3	73.3	83.9	28.1
6:09:00	124.7	139.7	106184	18187	87997	50.4	73.0	83.9	28.1
6:10:00	124.4	139.7	107605	18702	88904	50.0	72.4	83.9	28.0
6:11:00	124.4	139.4	105930	19002	86928	49.5	71.9	83.9	28.0
6:12:00	124.0	139.3	107754	19294	88460	49.2	71.9	83.9	28.0
6:13:00	124.1	139.6	109352	20110	89242	49.0	72.1	83.9	27.9
6:14:00	124.3	140.0	110384	20741	89643	49.0	72.8	83.9	27.9
6:15:00	124.4	140.1	110653	20936	89716	48.9	73.2	83.9	27.9
6:16:00	124.5	140.3	112038	21471	90567	48.9	73.6	83.9	27.8
6:17:00	124.6	140.5	112335	21825	90510	48.8	73.8	83.9	27.8
6:18:00	124.7	140.5	111246	21866	89381	48.7	74.0	83.9	27.8
6:19:00	124.8	140.4	110455	21592	88862	48.8	74.3	83.9	27.8
6:20:00	124.8	140.6	111515	21788	89727	48.9	74.5	83.9	27.8
6:21:00	125.1	140.4	108100	21686	86415	48.8	74.5	83.9	27.8
6:22:00	124.9	140.1	108150	21616	86534	48.6	74.4	83.9	27.8
6:23:00	124.5	139.9	108242	21187	87055	48.6	74.7	83.9	27.8
6:24:00	124.5	139.6	106941	20694	86247	48.6	75.1	83.9	27.8
6:25:00	124.5	139.6	106672	20940	85733	48.5	75.1	83.9	27.8
6:26:00	124.4	139.6	107308	20784	86524	48.6	75.3	83.9	27.8
6:27:00	124.2	139.4	107598	20696	86903	48.4	75.3	83.9	27.8
6:28:00	124.3	139.2	105697	20595	85102	48.3	75.5	83.9	27.8
6:29:00	124.0	139.5	109854	21375	88479	48.1	75.5	83.9	27.8
6:30:00	124.1	139.8	111254	22004	89249	48.0	75.6	83.9	27.8
6:31:00	124.4	139.8	109224	22111	87113	47.9	75.9	83.9	27.7
6:32:00	124.5	140.0	109698	22295	87403	48.0	76.5	83.9	27.8
6:33:00	124.6	140.0	109401	22242	87159	48.1	76.8	83.9	27.8
6:34:00	124.6	140.1	109967	22400	87566	48.1	77.1	83.8	27.8
6:35:00	124.6	140.2	109783	22321	87462	48.2	77.4	83.8	27.8
6:36:00	124.7	140.2	109903	22542	87361	48.1	77.4	83.8	27.8
6:37:00	124.7	140.4	110787	22985	87802	47.9	77.1	83.8	27.8
6:38:00	124.7	140.4	110589	23092	87497	47.9	77.2	83.8	27.8
6:39:00	124.8	140.5	110801	23243	87558	47.9	77.3	83.8	27.8
6:40:00	124.7	140.3	109910	22896	87014	47.9	77.4	83.8	27.7
6:41:00	124.7	140.3	110080	23056	87024	47.8	77.4	83.8	27.7
6:42:00	124.7	140.0	108030	22814	85216	47.7	77.4	83.8	27.8
6:43:00	124.6	139.7	106679	22348	84332	47.6	77.6	83.8	27.8
6:44:00	124.3	139.5	107012	22038	84973	47.6	78.0	83.8	27.8
6:45:00	124.3	139.4	107075	21953	85122	47.6	78.3	83.8	27.7

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
6:46:00	124.1	139.6	109048	21905	87143	47.8	78.8	83.8	27.7
6:47:00	124.1	139.6	109712	21651	88061	48.0	79.3	83.8	27.7
6:48:00	124.1	139.8	110617	21723	88894	48.1	79.2	83.8	27.7
6:49:00	124.4	140.0	110278	21970	88308	48.2	79.0	83.8	27.7
6:50:00	124.5	140.0	109981	22041	87939	48.2	78.8	83.8	27.7
6:51:00	124.4	140.0	110405	22181	88224	48.1	78.4	83.8	27.7
6:52:00	124.4	140.1	110886	22383	88503	48.0	78.2	83.8	27.8
6:53:00	124.5	140.0	109606	22326	87280	48.0	78.0	83.8	27.7
6:54:00	124.6	140.0	108779	22220	86559	48.0	77.9	83.8	27.7
6:55:00	124.6	140.0	109366	22146	87220	48.1	78.2	83.7	27.7
6:56:00	124.5	140.1	110737	22164	88573	48.2	78.3	83.8	27.7
6:57:00	124.5	140.1	110172	21919	88253	48.3	78.6	83.7	27.7
6:58:00	124.6	140.1	109953	21916	88037	48.3	78.5	83.7	27.7
6:59:00	124.6	140.1	110186	22264	87922	48.2	77.7	83.7	27.7
7:00:00	124.7	140.2	109924	22329	87595	48.2	77.2	83.8	27.7
7:01:00	124.7	140.2	109931	21939	87993	48.5	77.6	83.8	27.7
7:02:00	124.7	140.3	110278	21533	88745	48.7	77.9	83.8	27.7
7:03:00	124.8	140.4	109960	21721	88238	48.8	77.6	83.8	27.7
7:04:00	124.8	140.3	109493	21783	87710	48.6	76.7	83.8	27.6
7:05:00	124.9	140.3	109062	21934	87128	48.5	76.2	83.8	27.6
7:06:00	124.8	140.4	110511	22598	87913	48.2	75.7	83.8	27.6
7:07:00	124.8	140.2	109175	22422	86753	48.1	75.6	83.8	27.5
7:08:00	124.7	139.9	107485	22178	85307	48.0	75.9	83.8	27.5
7:09:00	124.6	139.7	106990	22111	84879	47.9	76.0	83.8	27.5
7:10:00	124.4	139.5	106538	21633	84905	47.9	76.5	83.7	27.5
7:11:00	124.3	139.5	107337	21553	85783	48.0	77.1	83.7	27.5
7:12:00	124.1	139.5	108793	21438	87355	48.0	77.5	83.7	27.4
7:13:00	124.1	139.3	107655	21079	86575	48.1	77.6	83.8	27.4
7:14:00	124.1	139.3	107662	20972	86690	48.1	77.9	83.8	27.4
7:15:00	124.0	139.7	110624	21515	89110	48.2	77.9	83.8	27.4
7:16:00	124.3	140.0	110950	22147	88802	48.1	77.7	83.7	27.4
7:17:00	124.3	140.1	111770	22604	89166	47.9	77.5	83.7	27.4
7:18:00	124.5	140.2	110787	22887	87900	47.8	77.5	83.8	27.4
7:19:00	124.6	140.4	111784	23184	88600	47.8	77.8	83.8	27.4
7:20:00	124.8	140.3	109797	22985	86812	47.8	78.1	83.8	27.5
7:21:00	124.7	140.4	110843	23140	87703	47.8	78.2	83.7	27.5
7:22:00	124.7	140.4	111466	23342	88123	47.8	78.2	83.7	27.4
7:23:00	124.7	140.4	111041	23364	87677	47.7	78.2	83.7	27.4
7:24:00	124.8	140.5	110603	23558	87045	47.7	78.3	83.8	27.4
7:25:00	124.8	140.4	110518	23400	87119	47.7	78.7	83.8	27.4
7:26:00	124.6	140.2	109854	22980	86874	47.7	78.8	83.8	27.4

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
7:27:00	124.6	139.9	108489	22458	86031	47.8	79.1	83.8	27.4
7:28:00	124.4	139.6	107372	21903	85469	47.9	79.4	83.8	27.4
7:29:00	124.3	139.7	108525	21922	86603	47.9	79.4	83.8	27.4
7:30:00	124.4	139.6	107648	21658	85990	48.0	79.4	83.8	27.4
7:31:00	124.4	139.6	107012	21479	85533	48.1	79.4	83.8	27.4
7:32:00	124.3	139.6	107924	21128	86796	48.3	79.4	83.8	27.4
7:33:00	124.4	139.6	107754	20904	86850	48.5	79.4	83.8	27.4
7:34:00	124.3	140.0	110752	21443	89308	48.5	79.4	83.8	27.4
7:35:00	124.6	140.4	111798	22156	89641	48.5	79.2	83.8	27.4
7:36:00	124.7	140.5	112010	22110	89900	48.6	79.0	83.8	27.5
7:37:00	124.7	140.5	111621	22046	89575	48.6	78.8	83.8	27.4
7:38:00	125.0	140.5	109585	22181	87404	48.6	78.3	83.8	27.4
7:39:00	124.1	139.4	108249	20624	87625	48.5	78.2	83.8	27.4
7:40:00	124.3	139.3	106488	20414	86074	48.5	78.2	83.8	27.4
7:41:00	124.3	139.2	105237	20128	85109	48.6	78.1	83.8	27.4
7:42:00	124.4	139.2	105279	20052	85227	48.7	78.2	83.9	27.3
7:43:00	124.4	139.7	108397	20689	87708	48.7	78.3	83.9	27.3
7:44:00	124.5	140.1	110179	21229	88950	48.8	78.4	83.8	27.2
7:45:00	124.9	140.2	108291	21381	86910	48.8	78.3	83.8	27.2
7:46:00	125.0	140.5	109380	21762	87618	48.9	78.4	83.9	27.2
7:47:00	125.1	140.5	109034	21762	87272	48.9	78.3	83.9	27.1
7:48:00	125.3	140.7	108722	21818	86905	49.0	78.2	83.9	27.2
7:49:00	125.4	140.4	106191	21210	84981	49.1	78.3	83.9	27.2
7:50:00	125.2	140.2	106319	20775	85544	49.2	78.3	83.9	27.2
7:51:00	125.1	140.1	106099	20108	85991	49.5	78.9	84.0	27.2
7:52:00	125.2	140.0	104587	19875	84711	49.6	78.9	84.0	27.2
7:53:00	127.8	141.9	99835	22969	76866	49.5	78.3	83.9	27.2
7:54:00	130.1	143.2	92780	24946	67834	49.5	78.0	83.9	27.2
7:55:00	131.3	143.1	83468	24643	58825	49.6	77.9	83.8	27.2
7:56:00	131.7	142.7	78371	23858	54513	49.7	77.9	83.8	27.2
7:57:00	131.4	141.9	74270	22377	51893	49.8	77.8	83.8	27.2
7:58:00	130.8	141.2	73577	21300	52277	49.9	77.8	83.8	27.3
7:59:00	130.4	140.5	71195	20158	51037	49.8	77.5	83.9	27.3
8:00:00	129.7	139.6	69830	18933	50897	49.8	77.2	83.9	27.3
8:01:00	129.1	138.9	69477	17797	51680	49.8	77.3	83.9	27.3
8:02:00	128.5	138.8	72595	17382	55213	49.9	77.6	83.8	27.3
8:03:00	128.2	138.8	74822	17253	57569	50.0	77.8	83.8	27.3
8:04:00	128.2	139.3	78336	17606	60730	50.3	78.5	83.8	27.3
8:05:00	128.5	139.7	79481	17942	61539	50.5	78.7	83.8	27.3
8:06:00	128.7	139.9	79743	18023	61720	50.7	78.8	83.8	27.3
8:07:00	129.0	140.3	79955	18557	61397	50.7	78.4	83.8	27.4

Time	Turbine Hx Inlet Temp °F	Turbine Hx Outlet Temp °F	Heat Production Btu/hr	Hose Loss Btu/hr	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
8:08:00	129.3	140.5	79311	18758	60554	50.8	78.3	83.8	27.5
8:09:00	129.5	140.7	79651	19017	60633	50.8	78.1	83.8	27.5
8:10:00	129.5	141.0	81213	19298	61915	50.9	77.9	83.7	27.5
8:11:00	129.8	140.7	76957	18663	58294	51.0	77.8	83.7	27.5
8:12:00	129.6	140.4	76215	17990	58225	51.2	77.6	83.7	27.5
8:13:00	129.4	140.2	76745	17639	59106	51.2	77.5	83.7	27.5
8:14:00	129.2	139.9	75479	17284	58195	51.1	76.9	83.7	27.7
8:15:00	129.0	139.8	76335	17113	59221	51.1	76.7	83.7	27.8
8:16:00	128.8	139.6	76307	16725	59582	51.2	76.7	83.6	27.7
8:17:00	128.6	139.3	75797	16240	59557	51.2	76.7	83.5	27.5
8:18:00	128.6	139.2	74801	15808	58993	51.3	76.7	83.4	27.6
8:19:00	128.3	139.4	78732	16186	62546	51.3	76.4	83.3	27.5
8:20:00	128.3	139.5	79127	16072	63055	51.5	76.3	83.3	27.6
8:21:00	128.2	139.4	79325	15609	63716	51.7	76.3	83.2	27.7
8:22:00	128.3	139.9	81927	16078	65849	51.9	76.1	83.2	27.9
8:23:00	128.6	140.3	82330	16552	65778	51.9	75.5	83.1	28.0
8:24:00	128.8	140.5	82479	16826	65653	52.0	75.0	82.9	28.0

Table G-2. Warehouse Heating Data (Dual Zones)

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
0:00:00	132.1	115.8	115278	49.7	44.9	75.5	27.8
0:01:00	132.4	115.8	116819	49.7	44.5	75.5	27.8
0:02:00	131.4	115.7	110761	49.7	44.4	75.5	27.7
0:03:00	129.8	114.0	111561	49.7	44.0	75.5	27.8
0:04:00	130.5	114.7	112042	49.7	44.0	75.5	27.7
0:05:00	130.8	114.4	115816	49.7	43.6	75.6	27.7
0:06:00	129.7	113.8	112413	49.7	43.6	75.6	27.7
0:07:00	130.8	114.4	116265	49.7	43.8	75.6	27.7
0:08:00	131.2	115.3	112438	49.7	44.2	75.6	27.7
0:09:00	130.7	114.9	111679	49.7	44.4	75.6	27.7
0:10:00	131.8	114.6	121409	49.8	44.5	75.6	27.7
0:11:00	132.2	115.3	119438	49.7	44.7	75.6	27.7
0:12:00	131.6	115.2	115865	49.7	44.0	75.6	27.7
0:13:00	131.1	115.1	112844	49.7	43.3	75.6	27.7
0:14:00	131.1	114.8	115097	49.7	42.7	75.6	27.7
0:15:00	131.8	115.1	118257	49.7	42.1	75.6	27.7
0:16:00	130.3	114.8	109661	49.8	41.8	75.5	27.7
0:17:00	130.9	114.6	114962	49.8	42.1	75.5	27.7
0:18:00	130.6	114.7	112535	49.8	42.6	75.5	27.7
0:19:00	130.7	114.8	112580	49.7	42.8	75.5	27.7
0:20:00	130.2	114.6	110025	49.7	43.1	75.5	27.7
0:21:00	130.6	114.7	112535	49.7	43.6	75.5	27.7
0:22:00	130.3	114.4	111867	49.7	43.5	75.5	27.7
0:23:00	129.6	114.1	109190	49.7	43.1	75.5	27.7
0:24:00	131.2	114.9	114692	49.7	42.6	75.5	27.6
0:25:00	131.2	114.8	116043	49.7	42.4	75.5	27.7
0:26:00	130.8	114.4	116265	49.7	42.4	75.5	27.7
0:27:00	131.4	115.1	115774	49.7	42.7	75.5	27.7
0:28:00	131.3	115.1	114782	49.7	42.8	75.5	27.7
0:29:00	131.1	115.1	113295	49.7	43.2	75.5	27.6
0:30:00	131.1	114.6	116447	49.7	43.5	75.5	27.7
0:31:00	131.3	115.6	111170	49.7	43.6	75.5	27.7
0:32:00	131.8	115.3	116452	49.8	43.4	75.5	27.7
0:33:00	129.9	114.5	108955	49.8	43.3	75.5	27.6
0:34:00	129.1	113.9	108040	49.8	43.2	75.5	27.6
0:35:00	129.8	113.7	113352	49.8	43.3	75.5	27.6
0:36:00	129.3	113.7	110363	49.7	43.7	75.5	27.6
0:37:00	130.3	114.1	114111	49.7	44.2	75.5	27.6
0:38:00	130.0	114.1	112141	49.6	45.0	75.5	27.6
0:39:00	130.0	114.9	106748	49.7	45.6	75.5	27.6
0:40:00	130.7	114.4	114828	49.7	45.9	75.5	27.6

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
0:41:00	131.1	114.9	114647	49.7	46.3	75.5	27.6
0:42:00	131.9	115.6	115143	49.7	46.3	75.4	27.6
0:43:00	132.1	115.3	118941	49.8	46.0	75.4	27.6
0:44:00	131.9	115.3	116950	49.8	45.7	75.4	27.6
0:45:00	130.9	114.7	114513	49.7	45.6	75.5	27.6
0:46:00	131.2	114.9	115187	49.7	45.9	75.5	27.6
0:47:00	131.9	115.5	115595	49.7	46.2	75.5	27.6
0:48:00	131.0	114.8	114558	49.7	46.8	75.5	27.6
0:49:00	130.7	114.3	115726	49.7	46.6	75.5	27.6
0:50:00	130.5	114.5	113391	49.7	46.6	75.5	27.6
0:51:00	129.8	114.1	110665	49.7	46.8	75.5	27.6
0:52:00	131.2	115.3	112481	49.7	46.4	75.5	27.6
0:53:00	130.0	114.2	111736	49.9	46.0	75.4	27.6
0:54:00	130.0	114.1	112141	49.9	45.9	75.5	27.5
0:55:00	130.5	114.7	112042	49.9	46.0	75.5	27.6
0:56:00	129.9	115.3	103551	50.0	46.0	75.5	27.6
0:57:00	131.4	115.0	115729	49.9	46.0	75.4	27.6
0:58:00	130.3	114.5	111418	49.9	45.8	75.4	27.6
0:59:00	130.0	114.6	108998	49.9	45.8	75.4	27.6
1:00:00	129.9	113.9	112993	50.0	45.6	75.4	27.5
1:01:00	130.9	114.8	113613	49.9	45.7	75.5	27.5
1:02:00	130.0	114.1	113081	50.0	45.5	75.4	27.5
1:03:00	131.2	114.8	116043	49.9	45.2	75.4	27.5
1:04:00	131.0	114.6	115908	49.9	43.9	75.5	27.5
1:05:00	131.4	115.6	111666	49.8	42.7	75.5	27.5
1:06:00	131.5	115.5	113562	49.9	42.5	75.5	27.5
1:07:00	131.7	114.9	118615	49.9	42.1	75.5	27.5
1:08:00	130.5	114.2	114693	49.8	42.4	75.5	27.5
1:09:00	130.0	113.7	115320	49.8	43.0	75.5	27.5
1:10:00	129.8	114.2	110216	49.7	43.7	75.5	27.5
1:11:00	130.2	114.0	114514	49.7	44.0	75.5	27.5
1:12:00	130.3	114.1	114111	49.8	43.8	75.5	27.5
1:13:00	131.2	114.6	117438	49.8	43.6	75.5	27.5
1:14:00	130.7	114.8	113074	49.7	43.7	75.5	27.5
1:15:00	132.4	115.6	118176	49.7	44.0	75.4	27.5
1:16:00	131.0	114.9	113657	49.7	44.0	75.4	27.5
1:17:00	130.6	115.1	109833	49.7	44.4	75.4	27.5
1:18:00	130.4	114.5	112404	49.7	44.4	75.4	27.5
1:19:00	130.5	114.9	110241	49.6	44.5	75.4	27.5
1:20:00	130.7	114.4	115771	49.7	44.4	75.4	27.5
1:21:00	130.7	114.4	114828	49.7	44.7	75.5	27.5
1:22:00	129.6	113.7	111878	49.6	44.5	75.5	27.5
1:23:00	130.5	114.4	113840	49.6	44.8	75.4	27.5

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
1:24:00	130.3	114.0	115500	49.6	45.2	75.4	27.5
1:25:00	130.9	114.8	114063	49.6	45.7	75.4	27.5
1:26:00	130.4	114.0	115994	49.6	46.3	75.4	27.5
1:27:00	131.6	115.3	114962	49.6	46.7	75.4	27.5
1:28:00	131.2	115.1	114286	49.6	47.0	75.4	27.5
1:29:00	131.3	114.8	116584	49.6	46.9	75.4	27.5
1:30:00	130.7	114.9	111679	49.6	46.7	75.4	27.5
1:31:00	130.1	114.7	109083	49.6	46.6	75.4	27.4
1:32:00	130.5	114.3	114244	49.6	46.5	75.4	27.5
1:33:00	130.7	114.7	113524	49.6	46.3	75.4	27.5
1:34:00	130.8	114.6	114918	49.7	46.3	75.4	27.5
1:35:00	130.7	114.4	115277	49.7	46.7	75.4	27.5
1:36:00	131.2	114.9	115187	49.7	46.8	75.4	27.5
1:37:00	130.9	114.8	113613	49.6	46.8	75.4	27.5
1:38:00	131.9	114.7	121954	49.6	46.7	75.4	27.5
1:39:00	130.4	114.5	112404	49.7	46.7	75.4	27.5
1:40:00	131.2	114.9	115187	49.7	48.7	75.4	27.5
1:41:00	130.7	114.6	113930	49.7	48.7	75.4	27.5
1:42:00	129.6	113.9	111027	49.7	49.3	75.4	27.5
1:43:00	130.2	114.9	108225	49.7	52.8	75.3	27.5
1:44:00	130.7	114.8	112129	49.6	54.4	75.3	27.5
1:45:00	130.6	114.6	112985	49.5	55.5	75.3	27.5
1:46:00	131.0	114.8	114558	49.5	57.3	75.3	27.5
1:47:00	131.9	115.2	117853	49.5	58.7	75.3	27.5
1:48:00	131.7	115.5	114555	49.4	59.5	75.3	27.5
1:49:00	130.8	114.8	113568	49.3	60.6	75.3	27.6
1:50:00	130.9	114.4	116760	49.3	60.9	75.3	27.6
1:51:00	130.5	114.5	112897	49.3	61.2	75.3	27.6
1:52:00	130.5	113.9	116935	49.2	61.1	75.3	27.6
1:53:00	129.5	113.7	111835	49.3	60.1	75.3	27.6
1:54:00	129.9	114.2	111200	49.3	59.3	75.3	27.6
1:55:00	130.8	114.6	114468	49.3	58.0	75.3	27.6
1:56:00	132.0	114.9	120651	49.2	57.2	75.2	27.6
1:57:00	131.0	114.9	113207	49.2	56.6	75.2	27.7
1:58:00	130.9	113.9	119900	49.2	57.0	75.2	27.7
1:59:00	131.1	115.1	113295	49.3	57.9	75.2	27.7
2:00:00	131.2	115.4	112030	49.4	59.1	75.2	27.7
2:01:00	131.7	115.6	113695	49.5	58.6	75.2	27.7
2:02:00	130.3	114.7	110069	49.5	57.3	75.2	27.7
2:03:00	129.8	114.3	109318	49.5	58.3	75.2	27.7
2:04:00	129.8	113.7	113799	49.6	59.9	75.2	27.7
2:05:00	129.9	113.7	114336	49.6	61.3	75.2	27.7
2:06:00	130.5	114.1	116533	49.5	62.8	75.2	27.7

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
2:07:00	130.0	114.0	113037	49.4	63.4	75.2	27.7
2:08:00	130.9	114.9	112712	49.3	63.5	75.2	27.7
2:09:00	130.3	114.4	112316	49.3	63.4	75.2	27.8
2:10:00	130.5	114.4	113346	49.2	63.6	75.2	27.8
2:11:00	130.8	114.1	118061	49.1	64.1	75.2	27.8
2:12:00	131.0	114.4	117255	49.1	64.5	75.2	27.8
2:13:00	130.5	114.6	112448	49.0	65.1	75.2	27.8
2:14:00	130.7	114.3	115726	48.8	65.9	75.2	27.8
2:15:00	130.4	114.8	110155	48.6	67.7	75.2	27.8
2:16:00	130.0	114.4	110838	48.4	69.3	75.2	27.8
2:17:00	130.0	113.8	114381	48.3	69.8	75.1	27.9
2:18:00	129.1	113.5	110277	48.3	70.3	75.1	27.9
2:19:00	129.5	113.6	112282	48.1	70.3	75.1	27.9
2:20:00	128.9	113.1	111443	48.0	70.3	75.1	27.9
2:21:00	129.4	113.6	111792	48.0	70.2	75.1	27.9
2:22:00	129.3	113.4	112597	47.9	70.1	75.2	27.9
2:23:00	130.0	113.9	113486	47.9	70.3	75.2	28.0
2:24:00	130.7	114.2	116623	47.9	70.6	75.2	28.0
2:25:00	131.0	114.5	116852	47.9	70.4	75.1	28.0
2:26:00	131.0	114.4	117255	47.9	71.0	75.1	28.0
2:27:00	130.2	114.4	111374	47.9	71.0	75.1	28.0
2:28:00	131.2	115.0	114242	47.8	70.8	75.1	28.1
2:29:00	132.5	115.1	122788	47.8	70.4	75.1	28.1
2:30:00	131.7	115.1	117263	47.8	70.1	75.1	28.1
2:31:00	130.7	114.8	112624	47.9	69.5	75.1	28.1
2:32:00	131.1	114.5	117346	47.9	68.5	75.1	28.1
2:33:00	130.7	114.5	114873	47.9	67.9	75.1	28.1
2:34:00	131.0	114.4	117255	47.9	68.3	75.1	28.1
2:35:00	129.8	114.2	110259	47.8	69.1	75.1	28.2
2:36:00	130.5	114.4	113346	47.8	69.6	75.1	28.1
2:37:00	129.8	114.1	111113	47.7	69.1	75.1	28.2
2:38:00	130.0	114.1	112141	47.8	68.3	75.1	28.2
2:39:00	130.3	113.9	115456	47.8	68.0	75.1	28.2
2:40:00	130.4	114.2	114649	47.9	67.8	75.1	28.2
2:41:00	131.5	114.4	121220	47.9	67.1	75.1	28.2
2:42:00	131.0	114.7	115503	47.9	67.7	75.1	28.2
2:43:00	130.4	114.4	113302	47.8	67.4	75.1	28.3
2:44:00	130.0	113.8	114873	47.7	67.1	75.0	28.3
2:45:00	130.3	113.9	115456	47.6	67.0	75.0	28.3
2:46:00	129.8	114.8	106214	47.5	67.5	75.0	28.3
2:47:00	130.9	114.6	114962	47.4	69.3	75.0	28.3
2:48:00	131.2	114.5	117842	47.3	70.8	75.0	28.3
2:49:00	130.5	114.4	114289	47.2	72.2	75.0	28.3

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
2:50:00	130.5	114.3	114244	47.1	72.8	75.0	28.3
2:51:00	131.5	114.9	117172	47.2	73.5	75.0	28.3
2:52:00	130.7	114.1	117566	47.0	74.3	75.0	28.4
2:53:00	131.2	115.6	110674	46.9	75.6	75.0	28.4
2:54:00	130.0	114.2	111244	46.7	77.0	75.0	28.4
2:55:00	129.8	114.1	111113	46.6	76.8	74.9	28.4
2:56:00	130.3	114.1	114604	46.4	77.4	74.9	28.4
2:57:00	129.7	114.1	110621	46.4	78.9	74.9	28.4
2:58:00	130.4	114.5	112404	46.3	79.2	74.9	28.5
2:59:00	131.2	114.7	116988	46.2	78.7	74.9	28.5
3:00:00	130.5	114.4	113346	46.2	79.0	74.9	28.5
3:01:00	130.3	114.6	110518	46.1	79.8	74.9	28.6
3:02:00	129.7	114.2	109276	46.0	80.4	74.9	28.6
3:03:00	130.3	114.3	112765	46.0	81.0	74.9	28.6
3:04:00	130.7	114.9	111723	46.1	81.7	74.9	28.6
3:05:00	130.7	114.2	116669	46.2	82.5	74.9	28.6
3:06:00	130.0	114.1	112633	46.1	83.0	74.9	28.7
3:07:00	129.6	113.7	112369	45.9	83.0	74.9	28.7
3:08:00	130.7	114.3	116220	46.0	83.0	74.9	28.7
3:09:00	131.4	114.4	120724	46.1	83.0	74.9	28.7
3:10:00	129.4	113.9	109554	46.1	82.7	74.9	28.7
3:11:00	131.0	114.9	113207	46.1	82.9	74.9	28.7
3:12:00	130.3	113.6	117694	46.0	82.5	74.9	28.7
3:13:00	130.9	114.2	118106	46.0	82.2	74.9	28.7
3:14:00	130.0	114.4	110838	46.1	82.2	74.9	28.7
3:15:00	130.0	114.4	110346	46.2	82.3	74.9	28.8
3:16:00	131.1	114.5	117346	46.2	82.2	74.9	28.8
3:17:00	130.5	114.3	114244	46.1	81.9	74.9	28.8
3:18:00	130.5	114.0	116981	46.0	81.8	74.9	28.8
3:19:00	130.3	114.2	113662	46.1	81.7	74.9	28.8
3:20:00	130.9	114.2	118106	46.0	82.2	74.9	28.8
3:21:00	130.7	114.1	117520	46.0	82.2	74.9	28.8
3:22:00	130.1	114.2	112677	46.0	82.2	74.9	28.8
3:23:00	130.3	114.4	112809	46.0	82.2	74.9	28.8
3:24:00	129.5	113.8	110940	46.0	82.1	74.9	28.8
3:25:00	129.8	113.9	112009	46.0	82.2	74.9	28.8
3:26:00	129.6	114.2	108293	46.0	82.2	74.9	28.8
3:27:00	129.5	113.1	115853	46.0	82.1	74.9	28.9
3:28:00	130.0	113.7	115276	46.0	82.3	74.9	28.9
3:29:00	129.6	113.7	112817	46.0	82.6	74.9	28.9
3:30:00	130.2	114.7	109575	46.0	82.4	74.9	28.9
3:31:00	130.0	114.1	113081	46.1	82.3	74.8	29.0
3:32:00	130.6	114.8	112086	46.0	82.4	74.8	29.0

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
3:33:00	130.5	114.5	113391	46.0	82.4	74.8	29.0
3:34:00	131.2	114.5	117842	46.0	82.0	74.8	29.0
3:35:00	130.8	114.2	117612	46.0	82.2	74.8	29.0
3:36:00	131.5	115.2	115368	46.0	82.4	74.8	29.1
3:37:00	130.6	114.3	115232	45.9	82.5	74.8	29.1
3:38:00	131.6	114.4	121716	45.9	82.5	74.9	29.1
3:39:00	131.9	115.1	118755	45.9	82.5	74.9	29.1
3:40:00	131.1	115.1	113295	45.9	82.5	74.8	29.1
3:41:00	130.9	114.5	115862	46.0	82.1	74.8	29.1
3:42:00	130.5	114.4	113346	46.1	82.0	74.8	29.1
3:43:00	129.8	114.1	111113	46.1	81.9	74.8	29.1
3:44:00	130.5	113.9	117429	46.2	81.9	74.8	29.1
3:45:00	129.6	113.9	111474	46.2	82.1	74.8	29.1
3:46:00	130.5	114.4	113840	46.2	81.8	74.8	29.1
3:47:00	130.1	114.2	112228	46.1	81.6	74.8	29.1
3:48:00	130.5	114.2	115636	46.1	81.1	74.8	29.1
3:49:00	131.4	114.8	117080	46.1	80.7	74.8	29.1
3:50:00	131.4	114.6	118926	45.9	80.6	74.8	29.2
3:51:00	131.4	115.1	115278	45.9	80.5	74.8	29.2
3:52:00	132.0	115.2	118847	46.0	80.6	74.8	29.2
3:53:00	131.0	114.8	114108	46.0	80.5	74.8	29.2
3:54:00	131.7	114.8	119065	46.1	80.3	74.8	29.2
3:55:00	130.7	114.1	117520	46.1	80.3	74.9	29.2
3:56:00	131.2	114.2	119639	46.2	80.6	74.9	29.2
3:57:00	130.0	114.1	112633	46.0	80.4	74.8	29.2
3:58:00	130.7	114.4	114828	45.8	80.4	74.8	29.2
3:59:00	129.9	113.8	113889	45.9	80.9	74.8	29.2
4:00:00	131.0	114.6	115952	45.8	81.4	74.8	29.2
4:01:00	129.8	113.8	113396	45.7	82.2	74.8	29.2
4:02:00	131.2	114.3	119684	45.7	82.6	74.8	29.3
4:03:00	130.8	113.7	121195	45.9	83.0	74.8	29.2
4:04:00	130.9	115.3	110006	45.8	83.2	74.8	29.2
4:05:00	130.6	114.2	116129	45.6	83.3	74.8	29.2
4:06:00	131.4	114.8	117080	45.5	83.5	74.8	29.3
4:07:00	130.8	114.8	113568	45.4	83.6	74.8	29.3
4:08:00	131.0	114.6	115457	45.5	83.7	74.8	29.3
4:09:00	130.8	114.7	114018	45.4	83.5	74.8	29.3
4:10:00	131.5	114.7	118973	45.3	82.8	74.8	29.3
4:11:00	131.9	114.7	121457	45.2	82.3	74.8	29.3
4:12:00	131.0	114.6	115908	45.2	82.3	74.8	29.4
4:13:00	130.6	114.3	115232	45.2	82.0	74.8	29.4
4:14:00	131.3	114.4	119732	45.2	81.5	74.8	29.4
4:15:00	130.5	114.2	114693	45.4	81.2	74.8	29.4

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
4:16:00	130.5	114.1	116533	45.4	80.9	74.8	29.4
4:17:00	130.0	114.1	112633	45.4	81.2	74.8	29.4
4:18:00	130.4	114.2	114649	45.3	81.4	74.8	29.4
4:19:00	131.4	114.4	120724	45.3	81.8	74.8	29.5
4:20:00	130.0	113.8	114873	45.4	81.9	74.8	29.5
4:21:00	130.3	114.3	113258	45.4	82.3	74.8	29.5
4:22:00	130.4	114.1	115546	45.3	83.0	74.8	29.5
4:23:00	130.4	114.1	115097	45.3	83.7	74.8	29.5
4:24:00	131.0	114.4	117255	45.3	84.6	74.8	29.5
4:25:00	130.7	115.4	108566	45.2	85.2	74.8	29.5
4:26:00	130.8	114.4	116265	45.3	85.7	74.7	29.5
4:27:00	130.9	114.6	115413	45.3	86.0	74.7	29.6
4:28:00	130.7	114.5	114873	45.2	86.1	74.7	29.6
4:29:00	131.0	114.5	116357	45.1	86.5	74.7	29.6
4:30:00	131.0	114.1	119993	45.1	86.7	74.7	29.6
4:31:00	131.4	114.6	118926	45.2	86.7	74.7	29.6
4:32:00	130.4	114.1	115546	45.2	86.6	74.7	29.6
4:33:00	131.3	115.0	115233	45.2	86.6	74.7	29.6
4:34:00	129.6	113.7	112817	45.2	86.5	74.7	29.6
4:35:00	131.0	113.9	120890	45.2	86.3	74.7	29.6
4:36:00	130.0	113.8	114381	45.1	85.4	74.7	29.6
4:37:00	129.4	113.7	110896	45.2	85.1	74.7	29.6
4:38:00	131.2	114.1	120536	45.3	85.0	74.7	29.6
4:39:00	129.6	113.9	111027	45.2	84.9	74.7	29.7
4:40:00	130.3	113.9	115903	45.2	84.5	74.7	29.7
4:41:00	131.0	114.6	115457	45.3	84.2	74.7	29.7
4:42:00	130.3	114.2	114155	45.1	84.0	74.7	29.7
4:43:00	131.7	114.7	119965	45.0	83.8	74.7	29.7
4:44:00	130.7	114.8	112580	45.0	83.5	74.7	29.7
4:45:00	130.9	114.4	116760	45.1	83.5	74.7	29.7
4:46:00	130.8	114.9	112668	45.2	83.5	74.7	29.7
4:47:00	130.7	114.3	115726	45.2	83.0	74.7	29.7
4:48:00	131.0	114.6	115457	45.1	83.0	74.7	29.7
4:49:00	131.1	114.4	117796	45.1	82.9	74.7	29.7
4:50:00	130.8	114.4	116265	45.2	82.9	74.7	29.7
4:51:00	130.9	114.2	117658	45.2	83.3	74.7	29.7
4:52:00	130.7	114.3	115726	45.2	83.4	74.7	29.7
4:53:00	130.2	114.4	111374	45.2	83.5	74.7	29.7
4:54:00	130.4	114.1	115546	45.2	83.5	74.7	29.8
4:55:00	131.2	115.1	114286	45.2	83.6	74.7	29.8
4:56:00	131.2	114.9	115638	45.2	83.4	74.7	29.7
4:57:00	131.7	115.0	117714	45.2	82.7	74.7	29.8
4:58:00	130.3	114.3	113258	45.4	81.8	74.7	29.8

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
4:59:00	129.6	113.5	113220	45.4	82.0	74.7	29.8
5:00:00	130.4	114.1	115097	45.4	81.8	74.7	29.8
5:01:00	129.8	113.4	115587	45.4	81.5	74.7	29.8
5:02:00	130.8	113.8	120300	45.5	81.0	74.7	29.8
5:03:00	129.6	113.6	113264	45.5	80.7	74.7	29.8
5:04:00	129.6	113.5	113711	45.5	80.9	74.7	29.8
5:05:00	130.0	114.1	112633	45.5	80.9	74.7	29.8
5:06:00	130.3	114.1	114559	45.5	80.6	74.7	29.9
5:07:00	131.3	114.6	117934	45.5	79.9	74.7	29.9
5:08:00	130.5	114.3	114738	45.6	79.8	74.7	29.9
5:09:00	131.4	114.7	118476	45.5	79.6	74.7	29.9
5:10:00	131.0	114.3	117704	45.6	78.8	74.7	29.9
5:11:00	130.9	115.0	112262	45.6	77.6	74.7	29.9
5:12:00	130.3	114.1	114604	45.6	77.6	74.7	29.9
5:13:00	130.2	113.9	115410	45.6	77.5	74.7	29.9
5:14:00	130.7	114.4	115322	45.6	77.4	74.7	30.0
5:15:00	130.1	114.5	110432	45.6	77.1	74.6	30.0
5:16:00	130.7	114.2	117117	45.8	76.2	74.6	30.0
5:17:00	129.4	113.6	111301	45.8	73.9	74.7	30.0
5:18:00	129.6	113.9	111474	45.8	73.6	74.7	30.0
5:19:00	131.2	114.2	120087	45.9	71.9	74.6	30.0
5:20:00	130.3	114.0	115008	45.9	72.4	74.6	30.0
5:21:00	129.9	114.1	112097	45.8	73.4	74.6	30.0
5:22:00	131.1	114.5	117346	45.8	74.0	74.6	30.0
5:23:00	130.1	113.9	114470	45.8	74.2	74.6	30.0
5:24:00	129.8	114.1	111605	45.9	73.2	74.6	30.0
5:25:00	130.7	114.5	114378	46.0	73.5	74.5	30.0
5:26:00	130.0	114.1	112633	45.9	73.6	74.5	30.0
5:27:00	131.1	114.2	119143	45.9	73.6	74.5	30.0
5:28:00	130.5	113.9	117429	45.9	73.7	74.6	30.0
5:29:00	130.5	113.7	118278	45.8	73.6	74.5	30.0
5:30:00	130.5	114.0	116981	45.8	73.5	74.6	30.0
5:31:00	130.0	113.7	114828	45.9	73.7	74.6	30.0
5:32:00	130.2	113.7	116753	45.9	73.9	74.6	30.1
5:33:00	129.7	113.8	112413	45.8	74.4	74.6	30.1
5:34:00	129.8	113.9	112009	45.8	75.1	74.6	30.1
5:35:00	130.1	113.8	115365	45.7	75.4	74.6	30.1
5:36:00	129.6	113.6	112773	45.7	74.9	74.6	30.1
5:37:00	131.0	114.1	119050	45.9	72.9	74.5	30.1
5:38:00	131.3	114.3	120181	45.9	72.3	74.5	30.1
5:39:00	131.2	114.6	116943	45.9	72.3	74.5	30.1
5:40:00	130.3	114.2	113662	45.9	72.9	74.5	30.1
5:41:00	131.2	114.6	117888	45.7	73.5	74.5	30.1

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
5:42:00	130.7	113.7	119759	45.7	72.4	74.5	30.1
5:43:00	131.2	114.2	120087	45.7	71.8	74.5	30.1
5:44:00	130.8	114.4	116265	45.7	72.0	74.5	30.1
5:45:00	130.9	114.2	118106	45.7	72.0	74.5	30.1
5:46:00	131.9	114.6	122357	45.8	72.1	74.5	30.1
5:47:00	131.1	114.9	114197	45.7	71.6	74.5	30.1
5:48:00	130.2	114.2	112721	45.7	71.9	74.5	30.1
5:49:00	131.4	114.3	120676	45.8	71.1	74.5	30.1
5:50:00	130.9	114.6	114962	45.7	71.1	74.5	30.1
5:51:00	131.4	114.5	119329	45.7	71.3	74.5	30.1
5:52:00	130.2	113.9	115410	45.6	71.1	74.5	30.1
5:53:00	130.5	114.4	114289	45.7	70.5	74.5	30.1
5:54:00	131.2	114.1	120536	45.7	70.1	74.5	30.1
5:55:00	130.0	113.7	115768	45.7	69.6	74.5	30.1
5:56:00	131.4	114.7	118476	45.7	69.0	74.5	30.1
5:57:00	130.7	114.6	113479	45.7	69.0	74.5	30.1
5:58:00	131.0	114.4	117750	45.7	69.8	74.5	30.1
5:59:00	130.8	114.4	116265	45.6	70.1	74.5	30.0
6:00:00	130.6	113.9	117923	45.7	70.1	74.5	30.1
6:01:00	131.1	114.4	118245	45.6	70.1	74.5	30.1
6:02:00	131.2	114.8	115593	45.6	69.4	74.5	30.1
6:03:00	131.2	114.5	118337	45.7	67.1	74.5	30.1
6:04:00	131.0	114.3	117704	45.7	66.0	74.5	30.1
6:05:00	131.2	114.4	118741	45.8	65.3	74.5	30.1
6:06:00	131.8	114.8	120059	45.8	65.4	74.5	30.1
6:07:00	131.7	115.0	118211	45.8	66.0	74.5	30.1
6:08:00	131.1	114.7	115997	45.8	66.2	74.4	30.0
6:09:00	132.3	114.9	122643	45.7	67.6	74.4	30.0
6:10:00	131.2	114.8	116538	45.7	67.1	74.4	30.1
6:11:00	131.5	115.5	113110	45.7	67.5	74.4	30.1
6:12:00	131.3	114.4	119732	45.8	65.3	74.4	30.1
6:13:00	131.5	114.6	119422	45.8	65.5	74.4	30.0
6:14:00	131.0	114.4	117301	45.8	65.5	74.4	30.0
6:15:00	130.6	114.2	115681	45.8	65.7	74.4	30.0
6:16:00	130.8	114.1	118509	45.8	65.0	74.4	30.0
6:17:00	130.4	114.0	115994	45.7	63.5	74.4	30.0
6:18:00	130.5	114.0	116487	45.7	64.3	74.5	30.0
6:19:00	130.6	114.7	112535	45.7	65.4	74.5	30.0
6:20:00	130.7	114.8	112580	45.6	66.5	74.4	30.0
6:21:00	130.0	113.7	114828	45.5	66.4	74.5	30.0
6:22:00	131.0	114.6	115457	45.5	67.0	74.5	30.0
6:23:00	131.4	114.5	119825	45.4	67.7	74.5	30.0
6:24:00	131.0	114.4	116806	45.4	68.5	74.5	30.0

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
6:25:00	131.4	114.6	118430	45.3	69.2	74.4	30.0
6:26:00	132.8	115.1	124786	45.3	70.1	74.4	30.0
6:27:00	131.6	114.9	117668	45.3	71.4	74.5	30.1
6:28:00	131.1	114.9	114647	45.3	71.3	74.5	30.1
6:29:00	131.7	114.8	119516	45.4	70.7	74.5	30.1
6:30:00	132.1	115.3	118941	45.4	70.4	74.5	30.0
6:31:00	131.7	115.2	116858	45.4	70.9	74.5	30.0
6:32:00	131.0	114.8	115053	45.5	70.2	74.5	30.0
6:33:00	131.6	114.9	117668	45.4	70.3	74.4	30.0
6:34:00	131.7	114.9	118164	45.4	69.2	74.4	30.0
6:35:00	132.1	115.1	119796	45.4	69.2	74.4	30.0
6:36:00	131.2	114.6	117438	45.4	69.5	74.4	30.0
6:37:00	131.6	115.2	115865	45.4	70.0	74.4	30.0
6:38:00	131.7	114.9	118164	45.3	70.7	74.4	30.0
6:39:00	131.9	115.6	115187	45.3	71.0	74.4	30.0
6:40:00	132.1	115.1	120247	45.4	71.3	74.4	30.0
6:41:00	131.4	115.4	113022	45.4	71.2	74.4	30.1
6:42:00	131.4	114.7	117980	45.4	71.7	74.4	30.1
6:43:00	131.0	114.8	114558	45.3	71.6	74.4	30.1
6:44:00	131.7	115.1	117760	45.5	70.0	74.4	30.1
6:45:00	131.2	114.3	119684	45.5	70.2	74.4	30.0
6:46:00	131.2	114.5	118337	45.6	69.4	74.4	30.0
6:47:00	131.3	114.4	119283	45.6	69.6	74.4	30.0
6:48:00	131.5	114.9	117172	45.6	69.6	74.4	30.0
6:49:00	131.2	114.4	118292	45.6	69.1	74.4	30.0
6:50:00	131.1	114.4	118245	45.6	69.1	74.4	30.1
6:51:00	130.7	114.8	112624	45.6	69.6	74.3	30.0
6:52:00	131.4	115.0	116225	45.6	68.9	74.3	30.1
6:53:00	131.0	114.7	115503	45.6	68.6	74.3	30.1
6:54:00	131.2	115.5	111082	45.6	68.7	74.3	30.0
6:55:00	131.7	114.9	118661	45.5	69.0	74.3	30.0
6:56:00	130.9	114.6	114962	45.4	69.3	74.3	30.0
6:57:00	131.1	114.9	114197	45.4	69.4	74.3	30.0
6:58:00	131.7	115.2	116361	45.3	69.9	74.4	30.0
6:59:00	131.9	115.3	117447	45.3	70.0	74.4	30.0
7:00:00	130.6	114.6	112985	45.3	69.9	74.3	30.0
7:01:00	131.5	114.7	118973	45.3	70.0	74.3	30.0
7:02:00	130.8	114.7	114018	45.2	70.3	74.3	30.0
7:03:00	130.7	114.4	114828	45.3	70.2	74.4	30.0
7:04:00	131.9	114.8	120557	45.4	70.0	74.4	30.0
7:05:00	131.6	115.0	117218	45.5	69.8	74.3	30.0
7:06:00	131.7	114.8	119562	45.5	69.6	74.4	30.0
7:07:00	132.7	115.2	123835	45.5	68.7	74.4	30.0

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
7:08:00	131.0	114.8	115053	45.5	68.9	74.3	30.0
7:09:00	131.6	115.3	115414	45.6	68.5	74.3	30.0
7:10:00	131.4	114.9	116676	45.6	68.3	74.3	30.0
7:11:00	131.7	115.3	115955	45.6	68.3	74.3	30.0
7:12:00	132.1	115.1	120295	45.6	67.7	74.3	30.0
7:13:00	131.9	115.5	116543	45.6	67.2	74.3	30.0
7:14:00	131.4	115.1	115323	45.6	67.8	74.3	30.0
7:15:00	130.7	114.7	113030	45.6	68.2	74.3	30.0
7:16:00	132.3	115.1	121742	45.6	68.1	74.3	30.0
7:17:00	131.3	115.1	114782	45.6	68.8	74.3	30.0
7:18:00	131.3	114.8	116584	45.6	69.0	74.3	30.0
7:19:00	131.9	115.1	118801	45.6	69.1	74.3	30.0
7:20:00	131.7	115.1	116812	45.6	68.4	74.3	30.0
7:21:00	130.7	114.2	116623	45.5	68.9	74.3	30.0
7:22:00	130.4	114.2	114200	45.4	70.0	74.3	30.0
7:23:00	131.0	113.7	122185	45.3	72.1	74.3	30.0
7:24:00	131.5	114.4	120771	45.2	73.5	74.3	30.0
7:25:00	131.4	115.1	115278	45.0	74.4	74.3	30.0
7:26:00	131.6	115.0	117218	44.8	74.7	74.3	30.0
7:27:00	131.4	114.5	119329	44.6	74.9	74.3	30.0
7:28:00	131.0	114.6	115908	44.5	75.6	74.3	30.1
7:29:00	131.4	114.6	119376	44.4	75.9	74.3	30.0
7:30:00	131.5	115.1	116270	44.4	75.5	74.3	30.1
7:31:00	131.3	115.3	112977	44.5	75.8	74.3	30.0
7:32:00	131.3	114.7	117484	44.4	76.0	74.3	30.1
7:33:00	131.5	115.3	114917	44.4	76.1	74.3	30.1
7:34:00	132.0	115.3	118396	44.5	76.2	74.3	30.1
7:35:00	130.9	114.7	114513	44.6	76.4	74.3	30.0
7:36:00	131.9	115.1	118801	44.6	76.9	74.3	30.0
7:37:00	132.4	115.8	117770	44.6	76.9	74.3	30.1
7:38:00	132.1	114.9	121149	44.6	76.6	74.3	30.1
7:39:00	131.0	114.5	116852	44.7	75.9	74.3	30.1
7:40:00	131.1	114.6	116447	44.7	75.8	74.3	30.1
7:41:00	131.6	114.7	119469	44.8	75.6	74.3	30.1
7:42:00	130.9	114.8	114063	44.8	75.5	74.3	30.1
7:43:00	132.3	115.4	119486	44.8	75.2	74.3	30.1
7:44:00	131.7	115.0	118211	44.8	75.3	74.2	30.1
7:45:00	130.9	115.4	109555	44.8	75.3	74.2	30.1
7:46:00	132.3	115.3	119937	44.8	75.7	74.3	30.1
7:47:00	131.4	115.4	113022	44.8	76.2	74.3	30.1
7:48:00	131.4	115.1	115278	44.8	76.2	74.3	30.1
7:49:00	131.3	115.0	115233	44.8	76.3	74.3	30.1
7:50:00	131.4	114.8	117080	44.8	76.4	74.3	30.1

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
7:51:00	131.4	115.0	116225	44.8	76.5	74.3	30.1
7:52:00	131.4	114.6	118926	44.8	76.5	74.3	30.1
7:53:00	131.6	115.2	115865	44.8	76.2	74.3	30.1
7:54:00	131.2	114.6	116943	44.8	76.1	74.3	30.1
7:55:00	131.8	115.2	117355	44.8	76.0	74.3	30.1
7:56:00	131.2	114.4	118741	44.8	75.4	74.3	30.1
7:57:00	132.0	115.0	120201	44.9	75.2	74.3	30.1
7:58:00	131.1	114.8	115097	44.9	75.2	74.3	30.1
7:59:00	131.2	115.1	113340	44.9	73.7	74.3	30.1
8:00:00	132.6	115.6	119673	44.9	72.9	74.3	30.1
8:01:00	132.0	115.3	118396	45.0	72.4	74.3	30.1
8:02:00	132.6	115.8	118815	45.1	72.6	74.3	30.0
8:03:00	131.7	115.7	112746	45.1	72.7	74.3	30.0
8:04:00	132.0	115.3	117945	45.1	72.9	74.3	30.0
8:05:00	132.0	115.4	117494	45.2	73.5	74.3	30.0
8:06:00	132.1	115.6	116635	45.2	73.2	74.3	30.0
8:07:00	131.4	115.2	114872	45.3	72.3	74.3	30.1
8:08:00	131.5	115.3	114465	45.3	72.5	74.3	30.0
8:09:00	131.0	115.0	112757	45.3	72.7	74.3	30.0
8:10:00	131.7	114.9	118615	45.3	72.2	74.3	30.0
8:11:00	131.0	114.8	114108	45.3	72.0	74.3	30.0
8:12:00	131.6	114.8	118569	45.3	71.5	74.3	30.0
8:13:00	131.5	114.8	118073	45.3	71.1	74.4	30.0
8:14:00	131.2	114.4	118292	45.3	70.4	74.4	29.9
8:15:00	132.8	115.2	124334	45.3	70.4	74.4	29.9
8:16:00	132.2	115.8	115821	45.3	70.9	74.3	29.9
8:17:00	131.4	114.8	118027	45.3	71.3	74.3	30.0
8:18:00	131.9	115.1	119252	45.3	71.3	74.4	30.0
8:19:00	132.1	115.6	116635	45.4	71.1	74.4	30.0
8:20:00	132.4	115.6	118675	45.3	71.9	74.4	29.9
8:21:00	131.8	115.5	115097	45.3	72.2	74.4	29.9
8:22:00	131.7	114.9	118661	45.3	72.7	74.4	29.9
8:23:00	132.1	115.3	118894	45.3	72.9	74.4	29.9
8:24:00	132.1	115.6	117134	45.1	72.3	74.4	29.9
8:25:00	131.2	114.9	115143	45.1	71.1	74.4	29.9
8:26:00	131.6	114.8	118569	44.8	70.0	74.4	29.9
8:27:00	130.7	114.8	112580	44.3	68.0	74.5	29.9
8:28:00	131.8	115.2	117355	44.0	67.2	74.5	29.9
8:29:00	131.8	115.2	117355	43.7	67.0	74.5	29.8
8:30:00	131.7	115.3	115910	43.6	66.6	74.5	29.9
8:31:00	131.5	115.6	112206	43.5	67.5	74.5	29.9
8:32:00	132.5	116.2	115550	43.4	68.0	74.5	29.9
8:33:00	133.2	115.8	123269	43.2	67.5	74.5	29.8

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
8:34:00	133.0	115.7	122220	43.1	66.9	74.5	29.8
8:35:00	131.7	115.2	116858	43.1	67.4	74.5	29.8
8:36:00	132.4	115.9	116864	43.1	67.8	74.6	29.8
8:37:00	131.8	115.4	116001	43.1	68.2	74.6	29.8
8:38:00	132.5	115.6	119627	43.2	68.5	74.6	29.8
8:39:00	132.1	115.3	118941	43.3	69.5	74.6	29.8
8:40:00	131.9	115.3	117899	43.5	70.4	74.6	29.7
8:41:00	132.5	116.3	114642	43.5	71.2	74.6	29.7
8:42:00	132.0	115.7	115233	43.5	71.8	74.6	29.7
8:43:00	131.9	115.2	118350	43.5	71.8	74.6	29.7
8:44:00	131.2	115.1	113835	43.6	72.3	74.6	29.7
8:45:00	130.5	114.6	112942	43.6	72.3	74.7	29.7
8:46:00	130.8	114.2	117163	43.6	72.3	74.6	29.7
8:47:00	131.2	114.4	118292	43.7	72.3	74.7	29.7
8:48:00	131.7	114.8	119562	43.5	71.4	74.7	29.7
8:49:00	132.2	115.3	119890	43.4	70.1	74.7	29.7
8:50:00	131.6	115.2	115865	43.5	69.8	74.7	29.7
8:51:00	132.1	115.2	119345	43.4	69.8	74.7	29.7
8:52:00	131.7	115.3	115458	43.3	69.7	74.8	29.7
8:53:00	132.1	115.6	116635	43.2	68.3	74.8	29.7
8:54:00	132.0	114.9	121101	43.1	67.7	74.7	29.7
8:55:00	131.5	115.1	116270	43.3	68.7	74.7	29.7
8:56:00	131.7	115.1	116812	43.2	68.9	74.7	29.6
8:57:00	132.2	115.4	118987	43.2	68.0	74.7	29.6
8:58:00	132.6	115.5	121077	43.1	68.3	74.7	29.6
8:59:00	132.2	115.8	116274	43.1	68.0	74.7	29.5
9:00:00	131.4	115.3	113925	43.3	69.0	74.7	29.5
9:01:00	131.8	115.4	116001	43.3	69.1	74.7	29.5
9:02:00	131.6	115.5	114058	43.1	68.5	74.8	29.5
9:03:00	132.6	116.1	116503	42.9	67.0	74.8	29.5
9:04:00	131.9	115.3	117447	42.8	65.3	74.8	29.5
9:05:00	131.2	114.6	117393	43.0	66.9	74.8	29.4
9:06:00	131.7	115.0	118211	43.0	68.4	74.8	29.4
9:07:00	132.1	115.0	120698	43.0	68.8	74.8	29.4
9:08:00	131.7	115.3	115910	42.9	68.4	74.8	29.5
9:09:00	131.3	115.3	112977	43.0	68.7	74.8	29.4
9:10:00	132.3	115.8	116772	43.1	69.4	74.8	29.4
9:11:00	131.4	115.5	113066	43.1	69.8	74.8	29.4
9:12:00	132.6	115.7	119720	43.0	69.6	74.8	29.4
9:13:00	131.9	115.3	116950	43.0	69.2	74.8	29.4
9:14:00	132.6	115.9	118362	43.1	70.0	74.8	29.4
9:15:00	131.9	115.6	115640	43.2	70.3	74.8	29.4
9:16:00	132.1	115.5	117585	43.1	69.7	74.9	29.4

Time	Blue Cart Inlet Temp °F	Blue Cart Outlet Temp °F	Heat Rate into B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	Zone Temp °F	Zone Humidity %RH
9:17:00	132.2	115.5	118535	43.0	68.9	74.9	29.4
9:18:00	132.1	115.5	117585	43.1	69.5	74.9	29.4
9:19:00	131.9	115.3	117447	43.2	70.0	74.9	29.4
9:20:00	131.7	114.9	118615	43.1	69.3	74.9	29.4
9:21:00	132.6	115.1	123786	43.0	68.4	74.9	29.4
9:22:00	131.4	115.3	113969	43.0	69.3	74.9	29.4
9:23:00	131.4	114.9	116179	42.9	69.3	74.9	29.4
9:24:00	131.4	115.1	114827	42.9	69.0	74.9	29.4
9:25:00	131.6	115.4	114511	42.9	69.4	74.9	29.4
9:26:00	132.1	115.1	120746	42.9	68.9	74.9	29.3
9:27:00	131.9	116.0	112426	42.9	68.8	74.9	29.4
9:28:00	131.7	115.1	117309	42.8	68.7	74.9	29.4
9:29:00	133.2	115.5	125530	42.9	68.8	74.9	29.4
9:30:00	131.7	115.2	116361	43.0	69.8	74.9	29.3
9:31:00	132.9	115.9	120361	43.0	70.6	74.9	29.3
9:32:00	131.4	115.1	115278	42.9	70.5	74.9	29.3
9:33:00	133.0	115.5	123577	42.9	71.2	74.9	29.3
9:34:00	132.5	115.5	120078	43.0	71.8	74.9	29.3

Table G-3. Warehouse Cooling Data (Single Zone)

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
13:10:00	66.1	67.9	24.4	22119	75.2	58.3	79.0	63.8
13:11:00	62.3	63.8	24.0	18491	75.2	58.6	79.0	63.8
13:12:00	58.7	60.2	23.9	18151	75.3	58.9	79.0	63.8
13:13:00	55.6	56.9	23.7	15453	75.4	58.5	79.0	63.8
13:14:00	53.4	54.2	23.9	10643	75.3	58.4	79.0	63.7
13:15:00	51.9	52.9	23.8	11478	75.5	58.6	79.0	63.3
13:16:00	49.6	50.6	27.5	13858	75.7	58.2	78.9	63.1
13:17:00	47.6	56.9	27.5	128236	75.7	58.7	78.9	62.5
13:18:00	49.1	58.2	27.6	126911	75.3	58.3	78.8	62.7
13:19:00	50.2	59.4	27.6	127366	75.2	58.6	78.8	62.7
13:20:00	52.0	60.1	27.6	113353	75.4	58.9	78.7	62.2
13:21:00	53.0	60.9	27.4	108846	75.2	59.0	78.7	62.0
13:22:00	53.1	60.8	27.9	108312	75.3	59.6	78.7	62.0
13:23:00	52.8	60.7	27.8	111004	75.0	59.4	78.7	61.8
13:24:00	52.0	60.2	27.8	114143	75.0	59.4	78.6	61.7
13:25:00	51.3	59.6	27.7	116412	75.0	59.7	78.5	61.4
13:26:00	51.0	59.2	27.7	115325	75.1	60.1	78.5	61.5
13:27:00	51.0	59.1	27.7	113243	75.0	59.6	78.5	61.4
13:28:00	51.9	59.4	27.8	104825	75.0	59.3	78.5	61.3
13:29:00	51.9	59.5	27.8	107337	74.9	59.8	78.5	61.1
13:30:00	51.8	59.4	27.7	107125	74.3	60.3	78.5	61.0
13:31:00	51.1	59.0	27.7	110375	74.2	60.7	78.4	60.7
13:32:00	50.2	58.4	27.7	114287	74.3	61.6	78.4	60.6
13:33:00	50.1	58.0	27.8	110987	74.7	62.2	78.4	60.6
13:34:00	51.2	58.5	27.7	101890	74.9	61.0	78.4	60.4
13:35:00	51.0	58.5	27.8	105279	74.9	60.3	78.3	60.3
13:36:00	50.8	58.4	27.7	105389	74.9	60.1	78.3	60.2
13:37:00	50.2	58.0	27.7	108186	75.0	60.4	78.2	60.1
13:38:00	49.5	57.5	27.7	111546	75.0	61.2	78.2	59.9
13:39:00	49.4	57.1	27.4	106161	74.8	61.3	78.2	59.8
13:40:00	50.5	57.7	27.7	100809	74.8	61.5	78.2	59.8
13:41:00	50.3	57.6	27.7	102793	75.2	60.8	78.2	59.6
13:42:00	50.1	57.5	27.7	103961	74.9	60.4	78.2	59.6
13:43:00	49.6	57.1	27.7	105725	74.9	61.0	78.2	59.4
13:44:00	48.8	56.6	27.7	109179	74.4	61.1	78.2	59.3
13:45:00	49.8	56.8	27.8	98128	73.8	61.4	78.2	59.2
13:46:00	49.8	57.1	27.8	102387	73.7	62.3	78.2	59.2
13:47:00	49.8	57.0	27.7	101375	73.6	62.6	78.2	59.0
13:48:00	-1000.0	-1000.0	27.7	0	73.5	62.5	78.2	58.9
13:49:00	48.8	56.3	27.7	106121	73.0	62.7	78.2	58.8
13:50:00	49.0	56.3	27.8	102382	73.0	63.5	78.1	58.6

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
13:51:00	49.6	56.7	27.8	99724	73.2	63.6	78.1	58.7
13:52:00	50.0	56.9	27.8	96681	72.9	63.8	78.1	58.7
13:53:00	49.9	56.9	27.7	97815	72.4	64.4	78.1	58.5
13:54:00	49.5	56.7	27.7	101002	72.4	65.6	78.1	58.6
13:55:00	49.4	56.5	27.7	99507	72.9	66.3	78.0	58.5
13:56:00	49.3	56.5	27.7	100771	73.4	66.1	78.0	58.5
13:57:00	49.4	56.5	27.7	99714	73.5	65.4	78.0	58.5
13:58:00	49.3	56.5	27.7	99623	73.8	65.2	77.9	58.6
13:59:00	49.3	56.4	27.7	99539	74.1	64.3	77.9	58.6
14:00:00	49.3	56.5	27.8	100178	73.7	63.4	77.9	58.5
14:01:00	49.3	56.4	27.7	99068	73.6	63.6	77.9	58.6
14:02:00	49.4	56.5	27.7	99145	73.4	63.4	77.9	58.4
14:03:00	49.4	56.5	27.7	99185	73.5	63.7	77.8	58.4
14:04:00	49.3	56.3	27.7	97933	73.4	63.8	77.8	58.4
14:05:00	49.2	56.3	27.7	98988	73.0	63.7	77.8	58.4
14:06:00	49.3	56.3	27.7	98763	73.0	65.0	77.8	58.5
14:07:00	49.2	56.3	27.7	98530	73.1	65.1	77.8	58.4
14:08:00	49.2	56.2	27.7	97850	72.9	64.5	77.7	58.3
14:09:00	49.3	56.2	27.7	97724	73.1	65.2	77.7	58.2
14:10:00	49.2	56.2	27.7	98228	73.2	65.5	77.7	58.3
14:11:00	49.1	56.1	27.7	98012	73.5	65.3	77.7	58.2
14:12:00	49.1	56.1	27.7	97367	73.8	64.4	77.7	58.2
14:13:00	49.2	56.1	27.7	96723	74.0	64.3	77.7	58.1
14:14:00	49.2	56.1	27.7	97133	73.6	64.0	77.7	58.1
14:15:00	49.0	56.0	27.7	97528	73.7	64.2	77.7	58.0
14:16:00	49.0	56.0	27.7	97241	73.3	64.1	77.6	58.1
14:17:00	48.9	55.9	27.7	98232	73.3	64.6	77.6	58.1
14:18:00	48.8	55.8	27.7	97871	73.5	65.0	77.6	58.1
14:19:00	48.8	55.8	27.7	97916	73.5	64.1	77.6	58.0
14:20:00	48.8	55.7	27.7	97203	73.0	64.4	77.5	58.0
14:21:00	48.7	55.7	27.7	97073	73.2	65.2	77.5	58.0
14:22:00	48.7	55.7	27.7	97846	73.4	65.2	77.5	57.9
14:23:00	48.6	55.6	27.7	97504	73.6	65.0	77.5	57.9
14:24:00	48.6	55.7	27.7	98524	73.6	65.1	77.5	57.9
14:25:00	48.6	55.6	27.7	97833	73.1	64.7	77.5	57.8
14:26:00	48.6	55.6	27.7	97360	73.2	64.9	77.4	57.8
14:27:00	48.7	55.7	27.7	97867	73.3	65.0	77.4	57.8
14:28:00	48.7	55.6	27.7	96622	73.7	65.1	77.3	57.7
14:29:00	48.5	55.5	27.7	97356	73.7	64.8	77.3	57.7
14:30:00	48.5	55.4	27.7	96510	73.1	64.7	77.3	57.7
14:31:00	48.5	55.4	27.7	95955	72.6	65.0	77.3	57.6
14:32:00	48.4	55.5	27.7	99278	72.1	65.6	77.3	57.6
14:33:00	48.4	55.4	27.7	96979	72.1	67.1	77.3	57.7

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
14:34:00	48.4	55.3	27.7	96056	72.1	67.4	77.3	57.7
14:35:00	48.4	55.3	27.7	96905	72.3	68.3	77.3	57.7
14:36:00	48.3	55.2	27.7	97192	72.4	67.8	77.3	57.7
14:37:00	48.4	55.3	27.7	96395	72.3	67.6	77.3	57.7
14:38:00	48.3	55.2	27.7	96664	72.6	67.2	77.2	57.7
14:39:00	48.3	55.1	27.7	96262	72.6	66.6	77.2	57.7
14:40:00	48.2	55.1	27.7	97091	72.4	66.3	77.2	57.7
14:41:00	48.2	55.1	27.7	96227	72.5	66.9	77.2	57.6
14:42:00	48.1	55.0	27.7	96598	72.6	66.8	77.2	57.5
14:43:00	48.1	55.0	27.7	96577	72.8	66.4	77.1	57.5
14:44:00	48.0	54.9	27.7	96443	72.6	65.6	77.1	57.5
14:45:00	48.0	54.9	27.7	96118	72.6	65.9	77.1	57.4
14:46:00	47.9	54.8	27.7	96559	72.4	65.7	77.1	57.4
14:47:00	48.0	54.9	27.7	96265	72.0	66.8	77.1	57.3
14:48:00	48.0	54.9	27.7	96849	72.4	67.3	77.1	57.3
14:49:00	47.9	54.8	27.7	96849	72.4	66.9	77.1	57.3
14:50:00	48.0	54.9	27.7	97084	72.2	66.8	77.1	57.3
14:51:00	48.0	54.9	27.7	96186	72.3	66.8	77.0	57.4
14:52:00	47.9	54.9	27.7	97531	72.1	66.8	77.0	57.3
14:53:00	48.0	55.0	27.7	97747	72.1	67.5	77.0	57.3
14:54:00	48.0	55.0	27.7	97035	72.2	67.4	77.0	57.3
14:55:00	48.0	54.9	27.7	96535	71.6	67.0	77.0	57.2
14:56:00	48.0	54.9	27.7	96430	71.8	67.9	77.0	57.3
14:57:00	48.0	54.8	27.7	95975	72.3	67.6	77.0	57.3
14:58:00	48.0	54.9	27.7	96391	72.6	67.6	77.0	57.2
14:59:00	48.0	54.9	27.7	96671	72.8	66.8	76.9	57.2
15:00:00	48.0	54.8	27.7	95556	72.9	66.3	76.9	57.3
15:01:00	47.9	54.8	27.7	96441	72.6	66.1	76.9	57.3
15:02:00	47.9	54.7	27.7	95040	73.0	66.5	76.9	57.2
15:03:00	47.9	54.7	27.7	94930	73.0	65.6	76.8	57.2
15:04:00	47.9	54.7	27.7	95543	72.6	65.1	76.8	57.2
15:05:00	47.9	54.7	27.7	95211	72.5	65.9	76.8	57.2
15:06:00	47.8	54.6	27.7	94393	72.2	66.1	76.8	57.2
15:07:00	47.8	54.6	27.7	94804	72.5	67.0	76.8	57.2
15:08:00	47.8	54.6	27.7	94383	72.5	66.1	76.8	57.2
15:09:00	47.7	54.2	27.7	91318	72.7	66.1	76.8	57.2
15:10:00	47.5	53.9	27.7	89378	72.3	65.2	76.8	57.0
15:11:00	55.6	53.8	27.7	-24509	71.8	65.9	76.7	57.0
15:12:00	61.3	59.0	27.7	-32585	71.3	66.9	76.7	57.0
15:13:00	64.6	62.9	27.7	-24027	71.3	67.6	76.7	57.0
15:14:00	66.5	65.5	27.7	-14292	71.2	68.1	76.7	57.0
15:15:00	67.9	67.5	27.7	-4710	71.8	68.6	76.7	57.1
15:16:00	68.8	68.9	27.7	433	72.2	68.6	76.7	57.0

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
15:17:00	69.6	69.9	27.7	4680	72.1	67.2	76.6	56.9
15:18:00	70.2	70.7	27.7	7040	71.6	67.4	76.6	56.9
15:19:00	70.6	71.2	27.7	9167	71.6	68.2	76.6	56.9
15:20:00	70.9	71.7	27.7	10844	71.2	68.0	76.6	56.8
15:21:00	71.2	72.1	27.7	12472	71.0	69.9	76.6	56.7
15:22:00	71.3	72.3	27.7	14038	70.8	69.6	76.6	56.7
15:23:00	71.4	72.5	27.6	15126	71.1	70.4	76.6	56.7
15:24:00	71.7	72.4	27.7	9050	70.9	70.5	76.6	56.7
15:25:00	51.6	56.0	27.6	60889	71.0	70.3	76.5	56.7
15:26:00	47.9	54.2	27.6	89290	71.4	70.6	76.5	56.6
15:27:00	47.6	54.2	27.6	91187	71.7	69.5	76.5	56.7
15:28:00	47.6	54.2	27.7	91224	71.5	68.8	76.5	56.7
15:29:00	47.5	54.2	27.7	92914	71.6	68.7	76.5	56.7
15:30:00	47.6	54.1	27.6	91667	71.5	68.7	76.5	56.8
15:31:00	47.6	54.2	27.6	92341	71.5	68.7	76.4	56.8
15:32:00	47.5	54.0	27.6	91176	71.6	68.6	76.4	56.8
15:33:00	47.4	54.1	27.6	92432	71.4	68.8	76.4	56.8
15:34:00	47.5	54.1	27.6	91898	71.5	69.1	76.4	56.7
15:35:00	47.4	54.0	27.6	91235	71.7	69.0	76.4	56.7
15:36:00	47.4	54.0	27.6	91862	71.9	68.8	76.3	56.7
15:37:00	47.4	54.0	27.6	91934	71.8	69.0	76.3	56.7
15:38:00	47.4	54.1	27.6	93988	71.1	69.0	76.3	56.8
15:39:00	47.5	54.1	27.6	93080	71.1	70.0	76.3	56.7
15:40:00	47.5	54.0	27.6	91456	71.0	70.4	76.3	56.8
15:41:00	47.4	54.0	27.6	92224	70.7	70.9	76.3	56.8
15:42:00	47.5	54.1	27.6	92605	70.3	71.7	76.3	56.8
15:43:00	47.5	54.2	27.6	93473	70.3	72.4	76.3	56.8
15:44:00	47.5	54.0	27.6	91765	70.5	73.1	76.2	56.9
15:45:00	47.5	54.0	x	x	70.7	73.1	76.2	57.0
15:46:00	47.5	54.0	27.6	91301	71.0	74.0	76.2	56.8
15:47:00	47.4	53.9	27.6	91077	70.8	73.3	76.2	56.9
15:48:00	47.4	54.0	27.6	91504	70.8	73.1	76.2	56.8
15:49:00	47.4	54.0	27.6	91581	71.0	73.1	76.2	56.6
15:50:00	47.4	54.0	27.6	91582	70.5	73.0	76.2	56.7
15:51:00	47.4	54.0	27.6	91250	70.2	73.7	76.1	56.7
15:52:00	47.3	54.0	27.6	92160	69.9	73.6	76.1	56.7
15:53:00	47.3	53.9	27.7	92436	70.1	74.9	76.1	56.8
15:54:00	47.3	54.0	27.7	92342	70.4	74.3	76.0	56.9
15:55:00	47.4	54.0	27.6	92329	70.8	74.3	76.0	57.0
15:56:00	47.4	53.9	27.6	91573	70.3	73.3	76.0	57.0
15:57:00	47.3	53.9	27.6	91504	70.2	73.4	76.0	57.1
15:58:00	47.3	53.9	27.6	91787	70.0	73.2	76.0	57.1
15:59:00	47.2	53.8	27.6	91272	70.5	73.5	75.9	57.0

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
16:00:00	47.2	53.8	27.6	91464	70.5	73.1	75.9	57.0
16:01:00	47.2	53.7	27.6	91313	69.9	72.6	75.9	56.9
16:02:00	47.2	53.8	27.6	92758	69.9	73.7	75.9	56.8
16:03:00	47.1	53.8	27.6	92973	69.4	73.9	75.9	56.8
16:04:00	47.2	53.8	27.6	91879	69.9	76.3	75.9	56.8
16:05:00	47.2	53.8	27.6	91579	69.7	75.0	75.8	56.8
16:06:00	47.2	53.7	27.5	91140	69.8	75.1	75.8	56.8
16:07:00	47.1	53.8	27.6	92384	70.2	75.7	75.8	56.8
16:08:00	47.2	53.7	27.5	91241	70.6	74.9	75.8	56.8
16:09:00	47.1	53.7	27.6	90962	70.6	73.3	75.8	56.8
16:10:00	47.1	53.7	27.6	91337	70.4	72.8	75.8	56.8
16:11:00	47.2	53.7	27.6	90787	70.2	72.6	75.8	56.8
16:12:00	47.0	53.7	27.6	91917	69.7	72.5	75.8	56.7
16:13:00	47.0	53.6	27.6	91858	69.6	73.4	75.8	56.7
16:14:00	47.1	53.7	27.6	91894	69.5	73.5	75.7	56.7
16:15:00	47.1	53.7	27.6	92300	69.8	73.7	75.7	56.9
16:16:00	47.0	53.7	27.6	92186	69.7	73.7	75.7	56.9
16:17:00	47.0	53.6	27.6	91147	69.4	73.4	75.7	56.9
16:18:00	47.0	53.6	27.5	91537	69.5	73.8	75.7	56.8
16:19:00	47.0	53.5	27.6	90951	69.4	74.0	75.7	56.8
16:20:00	46.9	53.6	27.6	92254	69.0	74.2	75.7	56.8
16:21:00	46.9	53.5	27.6	91283	69.2	74.6	75.7	56.7
16:22:00	46.9	53.4	27.6	91279	69.8	75.3	75.6	56.7
16:23:00	46.9	53.5	27.6	90781	70.3	75.0	75.6	56.7
16:24:00	46.8	53.5	27.6	92417	70.0	74.0	75.6	56.7
16:25:00	46.9	53.4	27.6	91705	69.6	72.9	75.6	56.7
16:26:00	46.8	53.4	27.6	91082	69.3	73.1	75.5	56.6
16:27:00	46.8	53.4	27.6	91540	69.3	73.8	75.5	56.6
16:28:00	46.8	53.3	27.6	91522	69.5	74.2	75.5	56.7
16:29:00	46.7	53.3	27.6	91372	69.6	74.2	75.5	56.7
16:30:00	46.7	53.3	27.6	91465	69.4	73.9	75.4	56.6
16:31:00	46.7	53.2	27.6	91053	68.9	74.2	75.4	56.5
16:32:00	46.7	53.4	27.6	92407	68.7	74.8	75.4	56.4
16:33:00	46.8	53.4	27.6	91401	68.9	75.8	75.4	56.4
16:34:00	46.8	53.4	27.6	91960	68.5	75.4	75.3	56.4
16:35:00	46.9	53.4	27.6	90562	68.5	76.0	75.3	56.5
16:36:00	46.9	53.4	27.6	90511	68.5	76.2	75.3	56.6
16:37:00	46.8	53.3	27.6	91181	69.0	77.2	75.3	56.5
16:38:00	46.8	53.3	27.6	90984	69.5	77.7	75.3	56.6
16:39:00	46.8	53.3	27.6	91272	69.3	76.0	75.3	56.6
16:40:00	46.8	53.3	27.6	90896	68.9	74.9	75.3	56.7
16:41:00	46.7	53.2	27.6	90663	68.9	75.1	75.2	56.7
16:42:00	46.7	53.3	27.6	92236	68.9	75.2	75.2	56.8

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity %RH	N. Zone Temp °F	N. Zone Humidity %RH
16:43:00	46.7	53.3	27.6	91474	69.4	75.5	75.2	56.8
16:44:00	46.7	53.3	27.6	92272	69.6	74.8	75.2	56.7
16:45:00	46.7	53.2	27.6	91259	69.7	74.3	75.2	56.8
16:46:00	46.7	53.2	27.6	91311	69.3	74.0	75.2	56.8
16:47:00	46.7	53.2	27.4	90439	69.1	74.2	75.2	56.8
16:48:00	46.6	53.2	27.6	92327	68.6	74.0	75.2	56.8
16:49:00	46.6	53.1	27.6	90971	68.7	75.2	75.1	56.6
16:50:00	46.6	53.2	27.6	91795	69.1	75.7	75.1	56.6
16:51:00	46.6	53.1	27.6	90943	68.8	74.9	75.1	56.6
16:52:00	46.5	53.1	27.6	90802	68.4	74.7	75.1	56.7
16:53:00	46.5	53.0	27.6	90644	68.5	75.8	75.1	56.7
16:54:00	46.4	53.0	27.6	91164	68.7	76.2	75.1	56.8
16:55:00	46.4	53.0	27.5	91099	68.4	75.3	75.1	56.8
16:56:00	46.5	53.0	27.6	90997	68.3	75.3	75.0	56.8
16:57:00	46.4	52.9	27.5	90566	68.1	75.4	75.0	56.8
16:58:00	46.6	53.0	27.6	88720	68.4	76.3	75.0	56.7
16:59:00	46.9	53.2	27.6	87690	68.7	76.6	75.0	56.7
17:00:00	47.5	53.7	27.6	85277	69.0	75.6	74.9	56.7
17:01:00	47.9	53.8	27.6	81511	69.2	74.7	74.9	56.7
17:02:00	48.6	54.2	27.7	77342	69.1	74.1	74.9	56.7
17:03:00	50.7	55.3	27.8	63780	69.1	74.2	74.9	56.8
17:04:00	53.1	56.9	19.1	36467	69.2	73.7	74.9	57.1
17:05:00	53.8	57.3	16.0	28081	69.3	73.5	74.9	57.1
17:06:00	54.2	57.5	16.0	27295	69.2	73.4	74.9	57.4
17:07:00	54.6	57.9	16.0	26301	69.0	73.3	74.8	57.6

Table G-4. Warehouse Cooling Data (Dual Zones)

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity RH%	Zone Temp °F	Zone Humidity RH%
14:21:00	60.7	61.8	28.2	15080	57.9	22.3	73.7	25.7
14:22:00	59.7	61.1	28.2	19285	57.5	22.4	73.6	25.7
14:23:00	57.6	58.3	28.3	9608	57.1	22.4	73.6	25.7
14:24:00	55.7	56.7	28.3	14254	57.1	22.3	73.6	25.8
14:25:00	54.0	54.9	28.2	13410	57.5	21.9	73.6	25.8
14:26:00	52.8	56.1	28.2	46362	58.0	21.6	73.5	25.8
14:27:00	52.6	57.1	28.2	64130	58.0	21.5	73.5	25.8
14:28:00	52.2	57.3	28.1	72276	58.1	21.2	73.5	25.9
14:29:00	52.3	56.9	28.2	66850	58.0	21.3	73.4	25.9
14:30:00	52.8	57.4	28.1	64687	58.1	21.2	73.4	25.9
14:31:00	52.0	57.0	28.1	70448	58.1	21.5	73.3	25.9
14:32:00	51.2	56.3	28.1	71993	58.3	20.8	73.3	26.0
14:33:00	51.2	56.0	28.1	68332	58.2	21.0	73.2	26.0
14:34:00	51.3	56.3	28.0	70726	58.0	20.8	73.2	26.2
14:35:00	50.4	55.6	28.0	73504	58.2	20.8	73.1	26.2
14:36:00	49.7	55.1	28.0	76443	58.3	20.5	73.1	26.2
14:37:00	49.7	54.8	28.0	72348	58.3	20.4	73.0	26.2
14:38:00	49.5	54.9	27.9	76389	58.5	20.6	73.0	26.3
14:39:00	48.9	54.3	27.9	75261	58.6	20.7	73.0	26.3
14:40:00	48.2	53.8	27.9	78543	59.1	20.6	72.9	26.3
14:41:00	48.3	53.6	27.9	75183	58.6	20.1	72.9	26.4
14:42:00	48.2	53.7	27.9	78011	58.4	20.6	72.9	26.5
14:43:00	47.8	53.3	27.8	77101	58.5	20.9	72.8	26.4
14:44:00	47.3	52.9	27.9	79073	59.0	20.6	72.8	26.5
14:45:00	47.7	53.0	27.9	75034	58.8	19.6	72.8	26.5
14:46:00	47.6	53.2	27.8	78729	59.0	19.2	72.7	26.5
14:47:00	47.3	52.9	27.8	78245	59.2	19.5	72.7	26.5
14:48:00	47.0	52.5	27.9	77275	59.4	19.5	72.6	26.5
14:49:00	47.5	52.9	27.8	74969	59.4	19.3	72.6	26.5
14:50:00	47.2	52.8	27.8	78931	59.5	19.4	72.6	26.7
14:51:00	47.1	52.7	27.8	78757	59.2	19.5	72.6	26.7
14:52:00	47.3	52.6	27.9	74833	59.3	19.3	72.6	26.7
14:53:00	47.6	53.0	27.8	75447	59.4	19.0	72.5	26.7
14:54:00	47.2	52.7	27.8	77077	59.7	19.2	72.4	26.7
14:55:00	46.9	52.5	27.8	78130	59.8	19.0	72.4	26.7
14:56:00	47.4	52.5	27.8	72393	59.7	18.5	72.4	26.8
14:57:00	47.2	52.8	27.7	78488	59.5	18.4	72.3	26.8
14:58:00	46.9	52.5	27.8	77874	59.6	18.4	72.2	26.8
14:59:00	47.1	52.5	27.8	76256	59.7	18.5	72.1	26.8
15:00:00	47.5	53.0	27.8	76557	59.7	18.5	72.0	26.9
15:01:00	47.1	52.7	27.8	79019	59.5	18.5	71.9	26.8

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity RH%	Zone Temp °F	Zone Humidity RH%
15:02:00	46.9	52.7	27.8	80018	59.8	18.8	71.9	26.9
15:03:00	47.3	52.7	27.8	75083	59.8	18.4	71.8	27.0
15:04:00	47.5	53.0	27.8	77813	59.7	18.4	71.7	27.0
15:05:00	47.2	52.8	27.8	78399	59.1	18.8	71.7	27.0
15:06:00	47.1	52.8	27.8	80577	59.0	19.0	71.7	27.0
15:07:00	47.2	52.7	27.8	77257	58.7	19.3	71.6	27.1
15:08:00	47.5	52.9	27.8	75734	58.9	19.5	71.6	27.1
15:09:00	47.2	52.7	27.8	77437	59.5	19.4	71.6	27.2
15:10:00	46.9	52.6	27.8	80135	59.6	18.7	71.6	27.2
15:11:00	46.6	52.2	27.8	77832	60.0	18.8	71.6	27.2
15:12:00	46.8	52.4	27.8	77272	60.2	18.5	71.5	27.2
15:13:00	46.4	52.1	27.8	79655	60.3	19.1	71.5	27.2
15:14:00	46.2	51.9	27.7	80122	60.1	18.6	71.5	27.2
15:15:00	46.0	51.6	27.8	79128	60.1	18.3	71.5	27.2
15:16:00	46.4	51.9	27.8	77073	59.9	18.0	71.4	27.3
15:17:00	46.1	51.9	27.7	80584	59.5	18.0	71.4	27.4
15:18:00	45.9	51.8	27.7	81865	59.6	18.4	71.4	27.4
15:19:00	45.7	51.4	27.8	79978	59.9	18.4	71.4	27.4
15:20:00	46.2	51.7	27.8	76450	60.2	18.4	71.4	27.4
15:21:00	46.0	51.7	27.8	80022	59.8	17.9	71.3	27.4
15:22:00	45.9	51.7	27.7	79964	59.8	17.8	71.2	27.4
15:23:00	45.5	51.3	27.8	79977	59.9	17.7	71.2	27.4
15:24:00	45.9	51.4	27.8	78141	59.9	17.7	71.2	27.4
15:25:00	46.0	51.7	27.7	79316	59.7	17.6	71.2	27.4
15:26:00	45.8	51.5	27.7	80388	59.1	17.7	71.2	27.5
15:27:00	45.5	51.3	27.7	81182	58.6	17.7	71.1	27.5
15:28:00	45.8	51.3	27.8	77471	58.9	17.8	71.1	27.5
15:29:00	46.0	51.6	27.7	77869	59.4	18.1	71.0	27.6
15:30:00	45.8	51.4	27.7	77373	59.9	17.9	71.0	27.6
15:31:00	45.6	51.3	27.7	80340	59.9	17.6	71.0	27.6
15:32:00	45.6	51.1	27.7	76609	59.7	17.3	71.0	27.6
15:33:00	46.2	51.6	27.7	74594	59.7	17.6	71.0	27.6
15:34:00	46.4	51.9	27.7	76067	59.8	17.7	71.0	27.6
15:35:00	46.5	52.0	27.7	76448	59.6	17.3	70.9	27.6
15:36:00	46.2	51.7	27.7	77203	59.3	17.3	70.9	27.6
15:37:00	46.5	51.9	27.8	74568	59.1	17.2	70.9	27.6
15:38:00	47.0	52.3	27.8	74388	59.1	17.4	70.9	27.7
15:39:00	46.9	52.2	27.7	73970	59.3	18.0	70.8	27.7
15:40:00	46.5	52.0	27.7	77280	59.7	18.0	70.8	27.7
15:41:00	46.6	51.9	27.8	74284	59.7	17.7	70.8	27.7
15:42:00	47.0	52.2	27.7	72695	59.6	17.6	70.8	27.8
15:43:00	47.0	52.3	27.7	74580	59.4	17.3	70.8	27.8
15:44:00	46.8	52.2	27.7	75748	59.5	17.6	70.7	27.7

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity RH%	Zone Temp °F	Zone Humidity RH%
15:45:00	46.3	83.1	27.7	515098	59.9	17.9	70.7	27.8
15:46:00	46.5	51.8	27.8	73110	60.0	17.6	70.7	27.8
15:47:00	46.9	52.2	27.7	74216	60.0	17.4	70.7	27.8
15:48:00	46.8	52.2	27.7	74268	59.4	17.6	70.7	27.8
15:49:00	46.3	51.8	27.7	77927	59.4	17.4	70.7	27.8
15:50:00	46.1	51.5	27.7	75971	59.3	17.0	70.7	27.8
15:51:00	46.5	51.7	27.7	73303	59.3	16.9	70.6	27.8
15:52:00	46.6	52.0	27.7	75194	59.5	16.9	70.6	27.8
15:53:00	46.7	52.1	27.7	75749	59.6	17.2	70.6	27.8
15:54:00	46.2	51.8	27.7	78441	59.7	16.9	70.6	27.9
15:55:00	46.3	51.7	27.7	75564	59.4	16.7	70.6	28.0
15:56:00	46.8	52.1	27.7	73413	59.8	17.2	70.6	27.9
15:57:00	46.9	52.2	27.7	75254	59.7	16.7	70.6	27.9
15:58:00	46.7	52.2	27.7	76050	59.6	17.0	70.6	27.9
15:59:00	46.2	51.8	27.7	77779	59.5	17.0	70.6	27.9
16:00:00	46.4	51.7	27.8	74589	59.7	17.2	70.5	27.9
16:01:00	46.9	52.1	27.8	74181	59.4	17.3	70.5	27.9
16:02:00	46.9	52.2	27.7	74234	59.0	17.0	70.4	27.9
16:03:00	46.6	52.1	27.7	76996	59.4	17.6	70.4	27.9
16:04:00	46.1	51.6	27.7	76953	59.3	17.4	70.4	27.9
16:05:00	46.5	51.7	27.7	73280	59.5	17.0	70.3	27.9
16:06:00	46.8	52.1	27.7	74736	59.7	16.9	70.3	27.9
16:07:00	46.7	52.0	27.7	74112	59.4	16.9	70.3	27.9
16:08:00	46.4	51.9	27.7	76836	59.4	16.8	70.3	27.9
16:09:00	46.0	51.5	27.7	77449	59.0	16.8	70.3	27.9
16:10:00	46.1	51.5	27.8	74909	58.9	16.9	70.2	27.9
16:11:00	46.4	51.8	27.7	76050	59.0	17.3	70.2	27.9
16:12:00	46.2	51.6	27.7	76226	58.9	17.3	70.2	27.9
16:13:00	45.6	51.2	27.7	78873	58.9	17.1	70.1	27.9
16:14:00	45.2	50.8	27.7	78309	59.0	17.1	70.1	27.9
16:15:00	45.6	51.0	27.8	75396	59.1	17.1	70.1	27.9
16:16:00	45.9	51.4	27.8	75970	59.6	17.0	70.1	27.9
16:17:00	45.8	51.2	27.7	75667	59.7	16.9	70.0	27.9
16:18:00	45.2	50.9	27.8	79066	59.6	17.1	70.0	27.9
16:19:00	45.9	50.6	27.9	67155	59.5	17.1	70.0	28.0
16:20:00	48.5	52.7	28.0	60172	59.4	16.7	70.0	28.0
16:21:00	50.7	55.1	28.0	62817	59.4	16.8	70.0	28.0
16:22:00	53.5	56.4	28.0	41460	59.6	16.9	70.0	28.0
16:23:00	53.0	57.7	27.7	65124	59.8	16.9	70.0	28.1
16:24:00	50.2	55.4	21.9	57240	59.7	16.8	70.0	28.1
16:25:00	48.8	55.6	27.8	95281	59.5	16.5	70.0	28.0
16:26:00	50.4	54.2	27.9	53121	59.4	16.5	69.9	28.0
16:27:00	51.0	55.2	28.0	58437	59.4	16.5	69.9	28.0

Time	Chilled Water Inlet Temp °F	Chilled Water Outlet Temp °F	Chilled Water Flow Rate gpm	Heat Removed From B7 Btu/hr	Ambient Temp °F	Ambient Humidity RH%	Zone Temp °F	Zone Humidity RH%
16:28:00	53.1	56.7	28.0	50789	59.4	16.5	69.9	28.0
16:29:00	53.9	57.5	28.0	49545	59.5	16.8	69.9	28.0
16:30:00	55.2	58.3	28.0	44634	59.4	16.8	69.9	28.0
16:31:00	55.9	59.1	28.0	44763	59.5	16.5	69.9	28.0
16:32:00	57.0	59.9	27.9	39917	59.3	16.5	69.9	28.0
16:33:00	57.6	60.3	16.1	22297	59.2	16.5	69.9	28.0

Appendix H. Breeden Press Release

For Immediate Release
Text also available at www.tristate.edu

TSU, REMC, and NET Together Again

With 7,200 volts coming in from the power lines, TSU students stood a respectful distance from the REMC transformer enclosure at the Angola Breeden YMCA while the PA-9 Plus Power Quality Monitor was being installed.

The students were electrical engineering seniors from Dr. Bob Whelchel's power systems class who had joined Dr. Larry Samuelson, TSU professor of electrical and computer engineering, to witness the installation of a PA-9 Plus Power Quality Monitor on Tuesday, Nov. 12. The installation was conducted by Jerry Wisdom, project engineer with NiSource Energy Technologies (NET), and Craig Burgi, marketing director at Steuben County REMC.

The monitor will record data on the currents and voltages going into the YMCA from the REMC transformer, which receives 7,200 volts of energy from the power lines and transforms them down to three-phase II grids of 277 volts. Data will be collected while two 60 KW micro-turbines, installed

Standing a safe distance from REMC's transformer behind the YMCA are (left to right) Kevin Snyder from Ottawa, OH; Doug McNeill from Trafalgar, IN; David Pruss from Farmer's Retreat, IN; Craig Burgi, marketing director with Steuben County REMC; Dr. Larry Samuelson, TSU professor of electrical and computer engineering; and Jerry Wisdom, project engineer with NiSource Energy Technologies (NET). Not pictured is electrical engineering senior Josh Warner of Oregon, OH. Warner will be working with Samuelson to collect and analyze the data from the power monitor.

at Breeden by NET, are running and then again for several days while the micro-turbines are turned off.

Once the testing and monitoring is complete, the micro-turbines will be used to generate a significant portion of the YMCA's energy needs. Craig Burgi has been the REMC facilitator throughout the entire process and believes it is a very exciting project. "We will still be serving the energy needs of the YMCA," Burgi said. "And I look forward to continuing to work with NET and Tri-State University on this project."

Samuelson and electrical engineering senior Josh Warner will collect the data, analyze it and then share their findings with REMC, NET and the Breeden YMCA.

"Ideally, when Josh and I look at the data, we won't see any harmonics, or spikes in voltage, when the micro-turbines are running, compared to the data collected while they are turned off," Samuelson said.

Should there be any difference, Wisdom will work with Burgi, Samuelson and Warner to troubleshoot and correct the problem.

Tri-State University is a career-oriented, comprehensive institution, granting over 40 associate and baccalaureate degrees in programs in the Allen School of Engineering and Technology, the Ketner School of Business, the School of Education, and the School of Arts and Sciences. The University, located in Angola, IN, has off-campus sites in Fort Wayne, South Bend and Merrillville, IN.

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Appendix I. Heat Storage Module Test

Sample results for one test are below.

LABTECH NOTEBOOK

Data file	$Cp_{(ave)}$	0.94	lb/ft^3
Time is 08:50:34.81.	$Density_{(ave)}$	8.48	lb/gal
Date is 5-29-2002.	Flow Rate	9	gal/min

Time	PCM Temp °F	Tube Temp °F	SHT F T °F	Ti Inlet Temp °F	To Outlet Temp °F	DHT F T °F	MHT F T °F	BTUH
0:00:00	118.341	135.4297	137.3797	133.3081	133.7931	132.7606	135.6543	2087.657
0:00:59	118.6722	135.2852	137.8212	132.8806	133.1455	132.7606	135.3652	1140.248
0:01:59	118.341	135.3574	137.7475	133.1655	133.2173	132.6894	135.2207	222.9704
0:02:59	117.8123	135.1407	137.7475	132.7383	132.715	132.4761	135.1486	-100.294
0:03:59	118.2748	132.5606	137.8949	121.7692	124.1058	132.7606	135.0765	10057.77
0:04:59	117.9443	130.5082	135.6242	114.5556	118.1887	132.1212	131.011	15638.49
0:05:59	117.6803	127.9922	133.0219	109.3019	114.3287	131.7669	128.0722	21637.6
0:06:59	117.7463	126.4028	131.165	106.7028	112.6541	131.4133	125.4538	25617.06
0:07:59	117.5485	124.9638	129.7493	104.4451	110.3615	130.5675	123.8194	25466.84
0:08:58	118.0104	123.1979	128.3445	101.4764	107.9114	129.5857	122.6033	27699.12
0:09:58	117.3509	121.7842	127.7159	99.2745	106.2351	127.9841	120.9279	29961.54
0:10:58	117.0221	120.7812	127.0199	97.1706	104.1471	126.4653	119.202	30029.98
0:11:58	117.2193	119.0559	126.3266	95.2304	102.2652	125.3687	117.8201	30280.93
0:12:58	116.9564	117.4127	125.8429	94.7488	101.1338	123.5331	116.6442	27483.9
0:13:58	116.7595	115.7846	125.0167	92.5649	99.8432	121.9171	115.2175	31329.06
0:14:58	116.8251	115.0084	124.5364	92.4971	98.6331	120.2492	114.2513	26412.09
0:15:58	116.0394	113.9146	124.331	90.8113	97.6431	118.7284	113.3544	29407.13
0:16:57	115.8435	113.0189	123.5797	89.9414	96.6587	117.0248	112.2078	28914.27
0:17:57	115.5826	111.874	123.0353	89.076	95.4016	115.7902	111.2581	27228.22
0:18:57	115.062	110.6107	122.3571	88.4135	94.4994	114.4356	110.1879	26196.44
0:19:57	114.6726	109.544	121.6815	87.4903	93.3269	113.2827	109.1243	25123.34
0:20:57	114.3487	108.6082	121.0756	87.0307	93.2581	112.3913	108.2533	26805.52
0:21:57	114.1547	107.5538	120.5387	86.1805	91.8216	111.6941	107.3248	24281.82
0:22:57	114.2194	106.6287	119.9366	86.1152	91.4134	110.8737	106.34	22805.83
0:23:57	113.5739	105.8309	119.2701	85.1401	90.4648	109.9944	105.4828	22919.89
0:24:57	113.1234	105.0368	118.7386	85.2049	90.2622	108.9327	105.1778	21768.88
0:25:56	112.7383	104.1251	117.9443	84.6223	89.5888	107.8156	104.1445	21378.04
0:26:56	112.8024	103.6408	117.5485	84.6223	89.2531	107.1365	103.4792	19933.04
0:27:56	112.29	102.7365	117.0878	83.9132	88.5169	106.46	102.4561	19816.39
0:28:56	112.0982	101.9446	116.4973	83.9132	88.0502	105.9697	102.0965	17807.5
0:29:56	111.4604	101.5859	116.0394	83.9132	88.1168	104.9324	101.9528	18094.18
0:30:56	111.2695	100.5854	115.5826	83.3352	87.784	104.2039	101.7376	19149.63
0:31:56	110.6982	99.7326	115.5826	83.3352	87.3193	103.9618	100.808	17149.35
0:32:56	110.8884	99.52	114.6078	83.015	86.5257	103.5992	99.7417	15111.63
0:33:55	110.3183	98.6725	113.8963	82.4402	86.1962	102.9966	99.5292	16167.51
0:34:55	110.1918	97.9694	113.3807	82.504	86.262	102.3602	98.4709	16176.12

Time	PCM Temp F	Tube Tem F	SHT F T F	Ti Inlet Te F	To Outlet T F	DHT F T F	MHT F T F	BTUH
0:35:55	109.687	97.3392	113.0592	82.2491	85.3424	101.6426	98.26	13314.95
0:36:55	109.687	97.0598	112.29	81.931	85.0806	101.2135	97.8391	13557.29
0:37:55	109.0579	96.5025	111.5241	81.8675	85.4079	100.2164	97.629	15239.47
0:38:55	108.3686	95.8777	111.3968	81.677	84.8845	99.5785	97.2096	13806.52
0:39:55	108.7443	95.3243	110.7616	81.4867	84.2326	99.2957	96.9306	11819.58
0:40:55	107.9938	94.8415	110.3183	81.1702	84.1025	98.5909	96.027	12621.93
0:41:54	108.8697	94.4975	110.0023	81.2334	83.9076	98.3098	95.2662	11510.95
0:42:54	107.9314	93.9486	109.2464	80.728	83.5833	97.889	94.4402	12290.49
0:43:54	107.2465	93.4016	108.5563	80.4129	83.4537	96.9113	94.5775	13088.97
0:44:54	106.8121	93.1968	108.1186	80.0984	83.0011	96.494	94.0286	12494.52
0:45:54	106.7501	92.4484	107.8067	80.0356	82.6141	96.0084	93.5498	11099.02
0:46:54	106.4406	91.9062	107.3708	79.8473	83.0657	95.7316	93.2768	13853.44
0:47:54	105.9465	91.5682	107.1844	80.2241	82.3566	94.9727	93.0724	9179.235
0:48:54	105.6384	91.2983	106.8121	79.6592	81.9712	94.9727	92.2571	9951.884
0:49:54	105.4538	90.9616	106.3787	80.0984	82.0354	94.0802	92.4606	8337.716
0:50:53	105.3923	90.6927	106.0081	79.91	82.1638	93.465	91.7833	9701.365
0:51:53	104.7174	90.0223	105.2694	79.2836	82.0996	93.3287	91.3783	12121.33
0:52:53	104.4726	89.8886	104.9625	79.5339	81.5226	92.8522	91.1089	8560.256
0:53:53	104.4114	89.6214	104.7174	79.7219	81.7788	92.9882	91.0416	8853.819
0:54:53	103.9231	89.1549	104.0451	79.1586	81.0115	92.2416	90.4371	7975.712
0:55:53	103.5578	88.8224	103.5578	79.0962	81.0753	91.6332	90.2362	8518.933
0:56:53	104.3503	88.6897	103.2539	79.0962	80.9477	91.4309	89.8349	7969.685
0:57:53	102.9506	88.0935	102.9506	78.9714	80.5656	91.2962	89.568	6862.151
0:58:52	103.3146	87.8292	102.5268	79.0338	80.8203	91.0943	89.4346	7689.896
0:59:52	102.89	87.6312	102.2851	78.5352	80.3749	91.3635	88.7033	7918.893
1:00:52	102.4059	87.4335	101.7426	78.473	80.6292	89.8881	88.9689	9281.251
1:01:52	102.5268	86.9075	101.5021	78.722	80.502	89.8881	88.7033	7661.917
1:02:52	102.3455	86.9732	101.1538	78.473	79.9941	89.8881	88.2396	6547.496
1:03:52	102.1041	86.4486	100.579	78.3486	80.2478	89.5546	88.0413	8175.008
1:04:52	101.442	86.5141	99.9346	78.1622	79.7407	88.8233	87.8432	6794.571
1:05:52	101.5622	86.1869	99.8632	78.5352	79.9941	88.6907	88.1074	6279.759
1:06:51	101.3819	85.5997	99.2927	78.2243	79.9307	88.8897	87.5135	7345.11
1:07:51	100.938	85.7952	99.1503	78.1002	79.3614	88.492	87.0532	5428.77
1:08:51	100.8662	85.5346	98.9371	78.0381	79.2352	88.2935	87.1189	5152.855
1:09:51	100.2923	85.2744	98.7241	78.2865	79.6142	87.8972	87.0532	5715.016
1:10:51	100.0061	85.0795	98.2989	77.9141	79.3614	87.9632	86.5286	6229.828
1:11:51	99.9346	84.9498	97.5221	78.909	79.6774	87.5677	86.7251	3307.538
1:12:51	99.8632	84.4963	97.3109	78.909	79.3614	87.6994	86.0057	1947.332
1:13:51	99.2215	84.561	97.3812	77.9141	79.046	86.8451	85.9405	4872.205
1:14:51	99.4351	84.4316	96.8892	78.1622	79.1721	87.1732	85.8752	4347.062
1:15:50	98.866	84.2377	96.4686	77.6663	78.7312	86.9762	85.4845	4583.807
1:16:50	98.795	83.9151	96.1887	78.1622	79.9307	86.5177	85.8752	7612.416
1:17:50	98.5113	83.5932	95.8396	78.722	78.8571	86.5831	85.3544	581.5309
1:18:50	98.3697	83.4645	95.7698	78.3486	78.6683	86.2563	85.0946	1376.132
1:19:50	98.2281	83.4645	95.352	78.0381	78.92	86.6486	84.9001	3796.093
1:20:50	97.5926	83.0793	94.8658	77.6045	78.6683	85.6695	84.9649	4579.072

Time	PCM Temp F	Tube Tem F	SHT F T F	Ti Inlet Te F	To Outlet T F	DHT F T F	MHT F T F	BTUH
1:21:50	97.1702	83.1434	94.5194	78.5352	78.7941	85.4744	84.7705	1114.422
1:22:50	97.0999	82.887	94.3119	77.419	78.3543	85.6695	84.641	4025.95
1:23:49	96.9594	82.887	94.3119	77.5426	78.4798	85.7997	84.5763	4034.129
1:24:49	96.7488	82.759	93.9666	77.4808	78.3543	85.4094	84.1886	3759.935
1:25:49	96.6086	82.631	93.8976	77.7282	78.417	85.4744	83.9951	2964.904
1:26:49	96.4686	82.3116	93.0722	77.3572	78.2915	85.1497	83.9951	4021.646
1:27:49	96.049	82.1202	92.7294	77.172	78.5426	84.6316	83.9951	5899.676
1:28:49	96.049	81.9291	93.0722	77.4808	77.853	84.6963	83.8019	1602.116
1:29:49	95.4911	81.6746	92.3874	77.1103	77.603	84.567	83.6732	2120.802
1:30:49	95.5608	81.6746	92.3874	77.1103	78.1035	84.3086	83.5445	4275.178
1:31:48	95.0045	81.4839	91.8416	77.2954	77.6655	84.2441	82.967	1593.076
1:32:48	94.9352	81.4839	91.9097	76.8638	77.291	84.2441	82.967	1838.86
1:33:48	94.381	81.1667	91.9779	76.6791	76.9796	83.9219	82.903	1293.487
1:34:48	94.1737	80.9767	91.1618	76.987	77.6655	83.4718	83.0311	2920.568
1:35:48	94.0356	80.7869	91.1618	76.5562	76.8552	83.4718	82.4554	1287.03
1:36:48	93.5532	80.6605	91.0262	76.4947	76.7931	83.087	82.2002	1284.447
1:37:48	93.5532	80.5973	90.5524	76.4333	76.6068	83.2152	81.9454	746.8217
1:38:48	93.3469	80.4711	90.4848	76.6791	76.4827	83.1511	81.691	-845.394
1:39:48	93.0722	80.3449	90.0799	76.6176	76.6688	82.6393	81.6275	220.3877
1:40:47	93.0722	80.1559	89.8778	76.3719	76.7309	82.7032	81.8181	1545.297
1:41:47	92.3191	80.2189	89.9452	76.5562	76.7931	82.1927	82.0728	1019.724
1:42:47	92.1143	79.59	89.005	76.2492	76.4827	82.5754	81.5005	1005.089
1:43:47	91.9779	79.7784	88.9381	75.7591	76.4206	82.0018	81.3101	2847.392
1:44:47	92.1825	79.8413	88.9381	76.4333	76.2347	82.2565	81.3736	-854.863
1:45:47	91.5014	79.5273	88.9381	76.0652	76.2967	82.0018	81.0567	996.4797
1:46:47	91.4334	79.9041	88.4702	76.004	76.4206	81.8746	81.2467	1793.233
1:47:47	91.1618	79.7156	88.4034	76.004	76.2967	81.7475	80.7405	1259.912
1:48:46	91.4334	79.59	88.4034	76.4947	76.4206	81.8746	80.8669	-318.96
1:49:46	91.0262	79.2765	88.5369	76.1265	76.2967	81.6204	80.8669	732.617
1:50:46	91.1618	79.3392	88.0036	76.1265	76.2347	81.557	80.1729	465.7413
1:51:46	90.9584	79.4646	87.937	76.7407	76.5447	81.6839	80.6773	-843.672
1:52:46	90.2148	79.1513	87.4056	76.3105	76.4206	81.24	80.6142	473.9197
1:53:46	90.7553	79.0887	87.3393	76.1878	75.9872	81.4935	80.9302	-863.472
1:54:46	90.4848	79.1513	87.4056	76.7407	76.6688	81.0502	80.6773	-309.49
1:55:46	90.0125	78.9011	87.0743	75.8203	76.2347	81.24	80.047	1783.763
1:56:45	89.7432	78.7762	87.1405	76.5562	76.4827	80.608	80.11	-316.377
1:57:45	89.6088	78.6514	86.942	76.4333	76.6068	80.4819	80.4249	746.8217
1:58:45	89.9452	78.6514	86.5457	76.3719	76.9796	80.9869	80.047	2615.813
1:59:45	89.005	79.0887	86.5457	76.2492	76.3587	80.4189	80.2359	471.3371
2:00:45	88.9381	78.402	86.2161	76.1878	76.0491	80.6711	79.4819	-597.027
2:01:45	89.072	78.402	86.0187	76.1265	76.0491	81.3667	79.2939	-333.164
2:02:45	88.6705	78.2152	85.3624	75.8815	75.9872	81.1767	79.4819	454.9802
2:03:45	88.4702	78.0908	85.4279	76.0652	76.0491	80.0413	80.3619	-69.3016
2:04:45	88.5369	77.7802	85.7559	76.1878	76.0491	80.23	79.3565	-597.027
2:05:44	88.2034	78.0908	85.2314	75.5147	75.6783	80.1041	78.9811	704.2077
2:06:44	87.804	78.0286	84.9699	76.3719	75.8636	80.23	79.1062	-2187.95

Time	PCM Temp F	Tube Tem F	SHT F T F	Ti Inlet Te F	To Outlet T F	DHT F T F	MHT F T F	BTUH
2:07:44	87.5383	77.7181	84.7739	76.1265	75.7401	79.9156	78.9811	-1663.24
2:08:44	87.273	77.6561	84.7087	75.8203	76.0491	79.79	79.1062	984.8577
2:09:44	87.0743	77.4082	84.3828	75.9427	76.0491	79.7273	78.8562	457.9933
2:10:44	87.1405	77.3463	83.9926	75.698	75.9254	79.5392	78.6066	978.8315
2:11:44	86.942	77.7181	84.2526	76.3719	76.1109	79.1636	78.9811	-1123.46
2:12:44	87.1405	77.4702	83.6681	76.4947	75.8018	79.5392	78.669	-2982.55
2:13:43	86.5457	77.4082	83.6033	76.0652	75.4933	79.2887	78.669	-2461.71
2:14:43	86.6777	77.4702	83.6033	76.2492	75.8636	79.1011	78.5443	-1659.8
2:15:43	85.8216	77.2845	83.2149	76.004	75.3701	78.7266	78.482	-2728.59
2:16:43	86.5457	77.4082	83.2149	75.7591	75.4933	78.9762	77.9843	-1144.12
2:17:43	85.8216	77.2226	82.892	75.5147	75.1239	78.9762	78.5443	-1682.18
2:18:43	85.2969	77.0372	82.8275	75.6369	75.3085	78.602	78.1708	-1413.58
2:19:43	85.166	76.9754	82.6985	75.698	75.555	78.6643	78.0465	-615.536
2:20:43	85.166	77.0372	82.5053	75.698	75.3701	78.789	78.0465	-1411.43
2:21:42	85.1006	76.667	82.6341	75.7591	75.3085	78.2908	77.7361	-1939.58
2:22:42	84.8392	76.667	82.5053	75.8203	76.1728	78.1665	78.2952	1517.318
2:23:42	84.7087	76.9137	83.0857	76.1265	75.9254	78.4152	78.233	-865.624
2:24:42	84.6434	76.9137	82.3123	76.004	75.6783	78.1665	78.1086	-1401.96
2:25:42	84.7739	76.9137	82.1196	75.8203	75.4317	78.1043	78.1086	-1672.71
2:26:42	84.7087	76.9137	82.0554	76.0652	75.6166	78.5397	77.6741	-1930.98
2:27:42	84.5782	77.099	82.1838	75.8815	75.8636	78.4774	77.6741	-77.0496
2:28:42	84.2526	77.0372	81.5426	75.6369	75.6166	78.2908	77.8602	-87.3803
2:29:42	84.3828	77.0372	81.7347	76.3105	75.9254	77.9802	78.1708	-1657.64
2:30:41	84.3177	77.2226	81.7988	76.2492	76.0491	78.1665	78.0465	-861.32
2:31:41	83.9926	76.9137	82.0554	75.9427	75.4933	78.353	77.7981	-1934.42
2:32:41	83.9276	76.9137	81.4787	76.004	75.8018	77.9181	77.9843	-870.359
2:33:41	83.7978	77.0372	81.6707	76.2492	76.1109	78.2908	77.8602	-595.305
2:34:41	83.8627	77.4702	81.4787	76.4947	76.2347	77.9802	78.1708	-1119.16
2:35:41	84.1225	77.099	80.9677	76.4333	76.0491	78.1043	78.1086	-1653.77
2:36:41	84.3177	77.0372	81.7347	76.1265	75.9872	78.1043	77.7981	-599.61
2:37:41	83.8627	76.7903	81.4787	76.004	75.8636	78.2286	77.6741	-604.344
2:38:40	83.3443	76.667	81.4787	76.2492	76.4206	78.1043	78.2952	737.7824
2:39:40	83.409	76.9754	81.6707	76.4333	76.1728	77.9802	77.9843	-1121.31
2:40:40	83.2149	77.099	81.3508	76.1878	76.1728	78.1043	77.9222	-64.5667
2:41:40	83.3443	77.1608	81.3508	76.6176	76.2347	78.4774	77.9222	-1648.17
2:42:40	83.6033	77.099	81.6707	76.8638	76.7931	77.9181	78.6066	-304.324
2:43:40	83.2149	77.9665	81.0953	76.8022	76.6068	77.8561	78.0465	-841.089
2:44:40	83.3443	77.3463	81.3508	76.4947	76.2967	78.602	77.9222	-852.281
2:45:40	83.2796	77.3463	81.4787	76.3719	76.3587	78.4152	78.1708	-56.8187
2:46:39	83.409	77.4702	81.223	76.8638	77.5406	78.5397	78.6066	2913.25
2:47:39	84.1225	77.5321	81.3508	76.8022	76.9174	78.353	78.0465	495.8724
2:48:39	83.0211	77.5321	81.0953	76.6791	76.6068	78.2908	78.482	-311.212
2:49:39	83.3443	77.7181	81.2869	76.987	76.7931	78.5397	77.9843	-834.632
2:50:39	83.1503	77.4702	80.7766	76.9254	76.9796	79.1011	78.1086	233.3011
2:51:39	83.3443	77.6561	81.1591	77.172	76.7309	78.7266	78.0465	-1898.69
2:52:39	82.8275	77.5941	80.9677	77.172	77.1041	78.7266	78.669	-292.272

Time	PCM Temp F	Tube Tem F	SHT F T F	Ti Inlet Te F	To Outlet T F	DHT F T F	MHT F T F	BTUH
2:53:39	83.5385	77.8422	80.522	77.419	77.3534	79.0386	78.233	-282.372
2:54:39	82.892	77.6561	81.0953	77.4808	77.5406	78.4774	78.7938	257.406
2:55:38	83.2796	77.7802	80.9677	77.5426	77.6655	78.6643	78.8562	529.0167
2:56:38	83.0211	77.9043	81.2869	77.6663	77.603	78.602	78.7314	-272.472
2:57:38	82.9565	78.153	81.223	77.5426	77.728	78.4152	78.8562	798.0447
2:58:38	83.1503	77.7181	81.0953	77.419	77.603	78.4152	78.669	792.0184
2:59:38	83.0857	78.0908	81.1591	77.9141	77.7905	78.6643	78.669	-532.03
3:00:38	83.0857	77.9665	81.1591	77.4808	77.6655	79.4139	78.2952	795.0315
3:01:38	82.763	77.8422	80.7766	78.4108	77.7905	78.602	78.669	-2670.05
3:02:38	82.8275	78.2152	81.6707	78.1002	78.0408	78.8513	78.9186	-255.684
3:03:37	82.892	78.0908	81.4787	77.419	77.728	78.7266	78.669	1330.074
3:04:37	82.3766	78.153	81.927	77.7282	77.728	78.4774	78.9186	-0.86089
3:05:37	83.0211	78.3397	81.1591	78.1622	77.9156	78.9138	79.0436	-1061.48
3:06:37	83.0857	78.4643	81.1591	77.9761	77.728	79.2262	78.9811	-1067.93
3:07:37	82.5697	78.9636	81.2869	78.3486	78.2288	78.5397	78.8562	-515.673
3:08:37	82.8275	78.4643	81.2869	78.3486	78.2915	78.9138	79.1687	-245.784
3:09:37	82.5697	78.7138	81.2869	78.1002	78.1035	79.2262	78.7314	14.20468
3:10:37	83.0857	78.589	81.1591	78.473	78.2288	79.0386	78.7938	-1051.15
3:11:36	83.2796	78.589	81.223	78.7843	78.6055	78.789	79.3565	-769.635
3:12:36	82.5697	78.7762	81.4147	78.3486	78.2915	79.2262	78.9186	-245.784
3:13:36	82.3123	78.7762	81.0953	78.4108	78.92	79.0386	79.2313	2191.825
3:14:36	82.9565	78.7138	81.2869	78.909	78.3543	79.4139	79.1687	-2387.68
3:15:36	82.6985	78.7762	80.9677	78.2243	78.3543	79.4139	78.669	559.5782
3:16:36	82.3766	78.7138	80.6492	78.7843	78.8571	78.9762	79.6073	313.3638
3:17:36	82.3123	78.7762	80.4584	78.7843	78.92	79.0386	80.047	584.1136
3:18:36	82.5697	78.7138	81.2869	79.0338	78.7312	79.1011	79.1687	-1302.53
3:19:36	82.5697	78.7138	80.4584	79.2211	78.8571	79.6019	78.9811	-1566.82
3:20:35	82.441	79.0262	81.223	78.5974	78.6055	79.5392	78.9811	34.86603
3:21:35	82.3123	78.6514	81.1591	79.0338	79.3614	79.1011	79.4819	1410.137
3:22:35	82.763	78.9636	80.522	78.909	79.109	79.5392	79.1062	860.8896
3:23:35	81.927	79.1513	81.0953	78.909	79.2352	79.0386	79.5446	1404.111
3:24:35	82.3766	79.2765	80.6492	79.2836	79.2983	79.2887	79.5446	63.27539
3:25:35	82.441	79.2139	81.0315	79.4087	79.3614	79.2887	79.7328	-203.6
3:26:35	82.9565	79.4019	80.5856	79.0338	79.2983	79.2887	79.4819	1138.526
3:27:35	82.3123	79.1513	80.6492	79.4087	79.2352	79.2887	79.67	-746.822
3:28:34	82.3766	79.4646	80.7129	79.5965	79.4878	79.2262	79.8584	-467.893
3:29:34	82.763	79.4646	80.5856	79.5339	79.2983	79.8528	79.2939	-1014.13
3:30:34	82.1838	79.59	80.8403	79.6592	79.6774	79.1636	80.1729	78.34095
3:31:34	82.248	79.4646	80.2678	79.5339	79.4878	79.79	79.7956	-198.435
3:32:34	82.1838	79.4019	80.522	79.7219	79.6774	79.4765	79.7956	-191.548
3:33:34	82.3123	79.967	80.7766	79.7219	79.6142	79.5392	79.6073	-463.589

Appendix J. Heat Storage Module Results

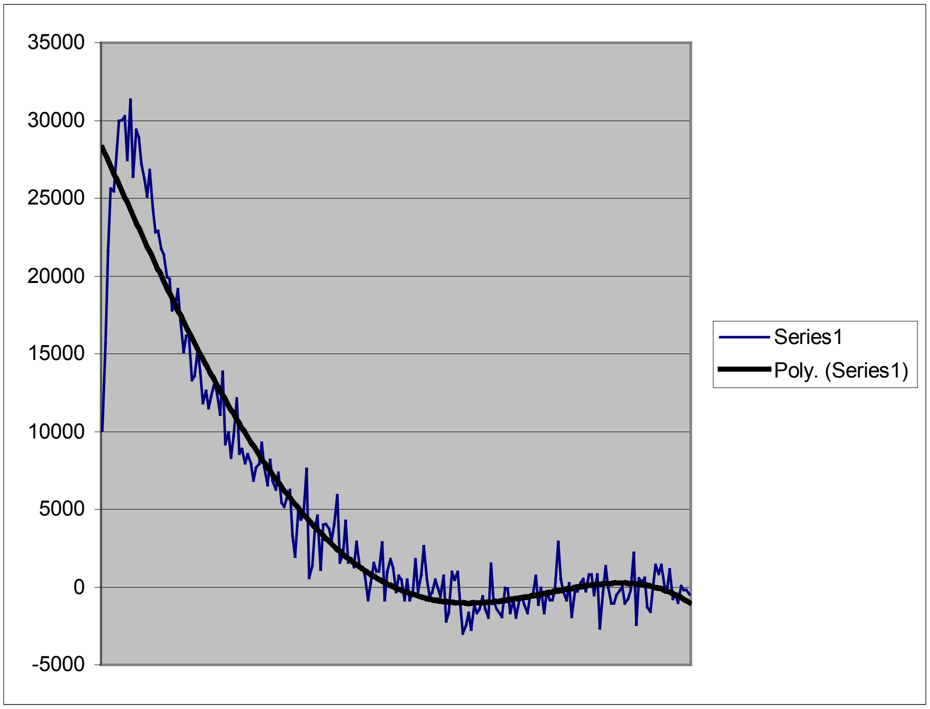


Table J-1. Rate of heat addition

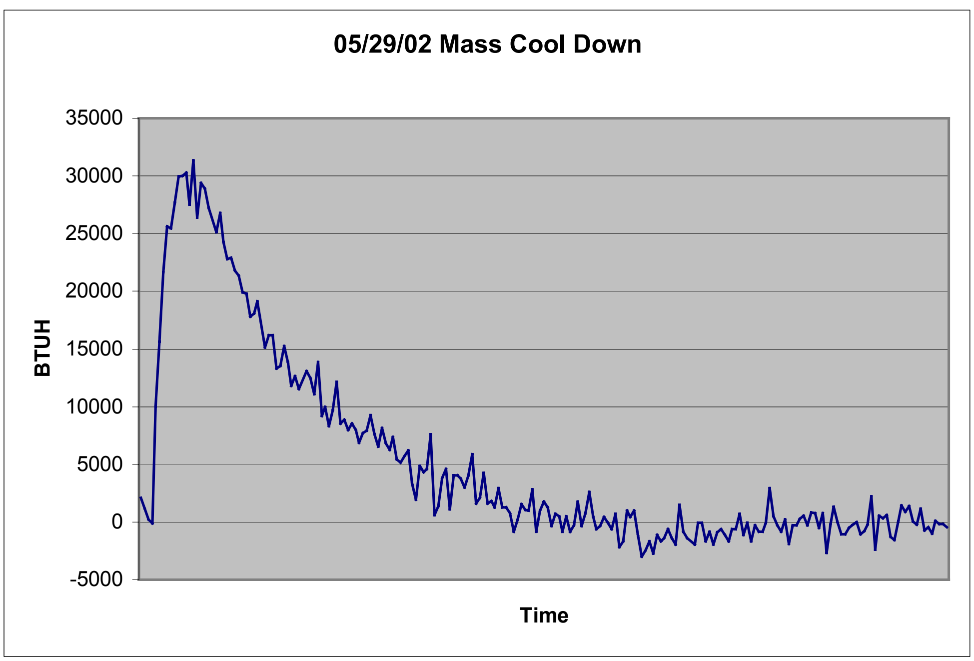
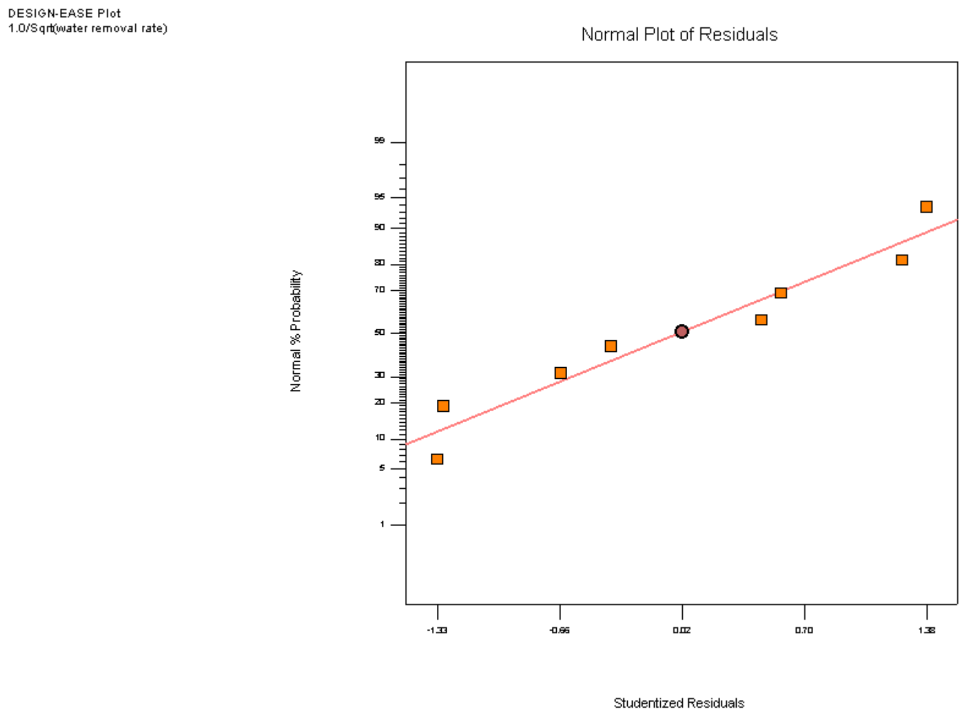
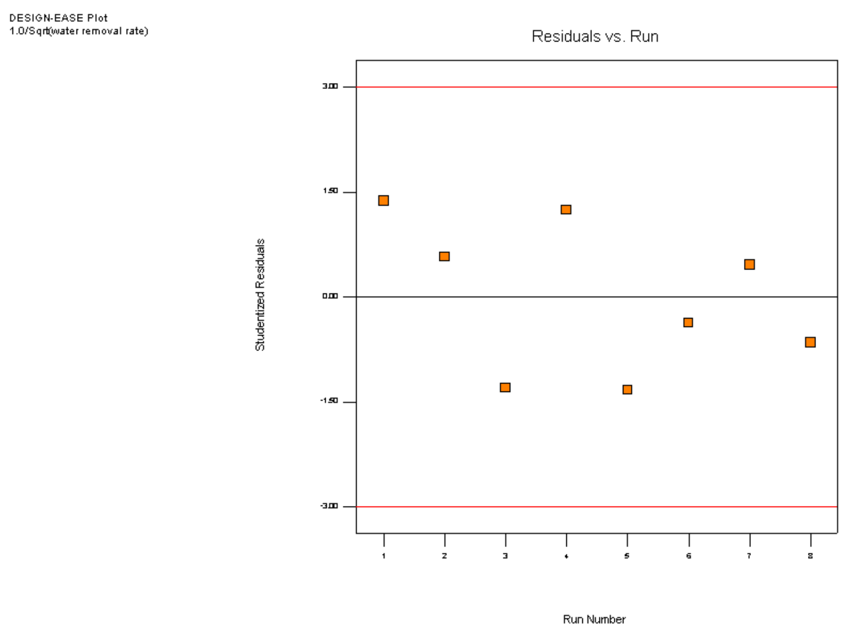


Table J-2. Rate of heat removal

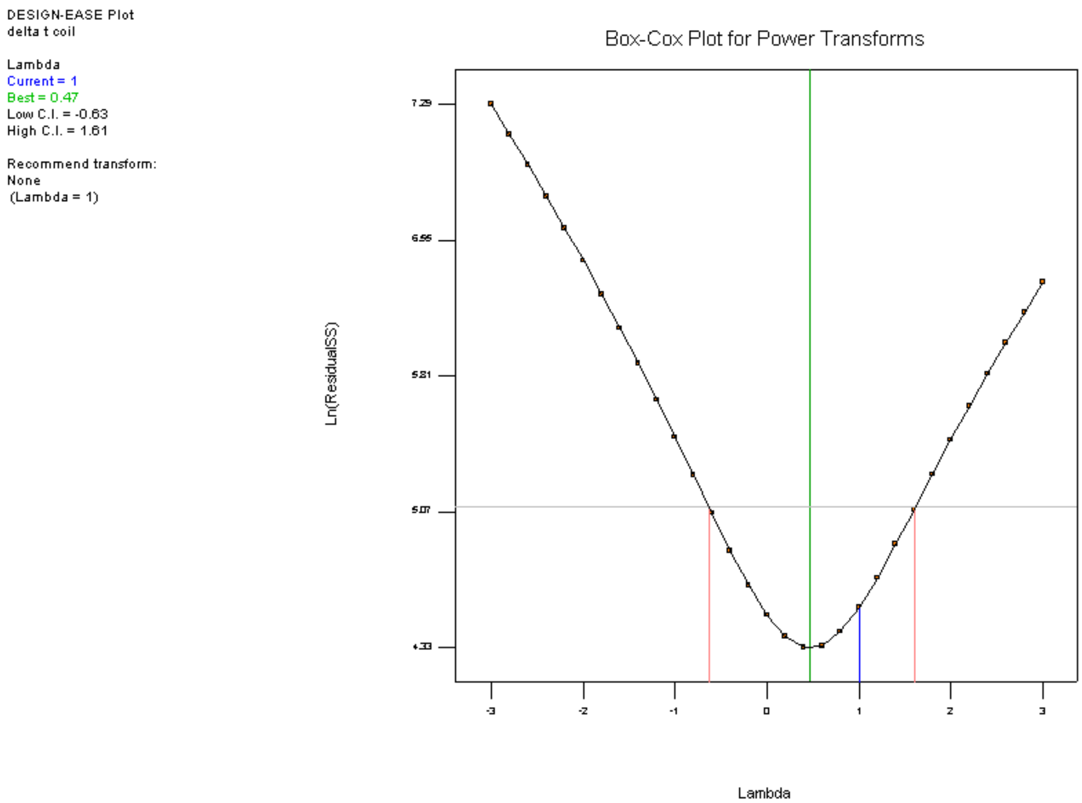
Appendix K. Chesterton Desiccant Test

Water Removal Rate

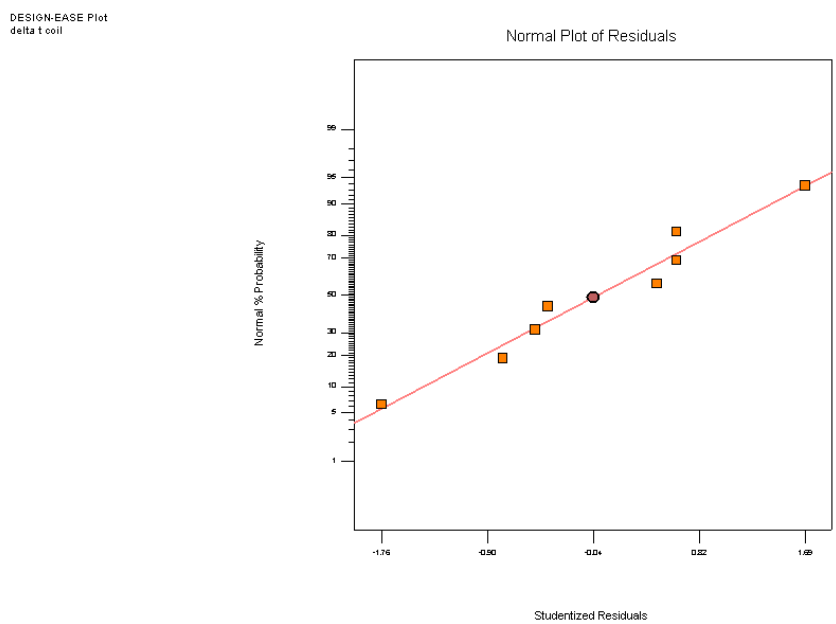




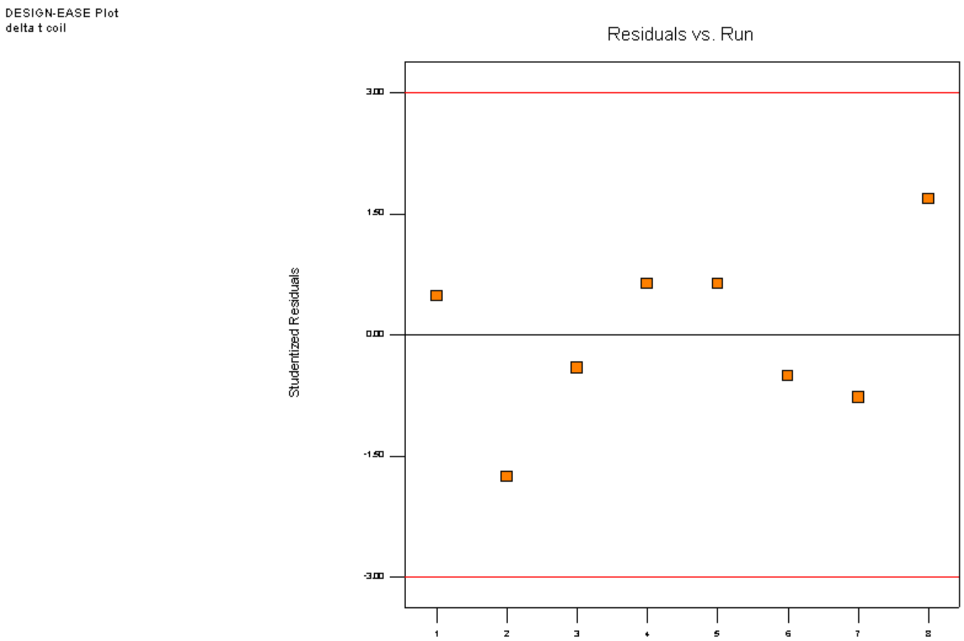
Delta T Coil



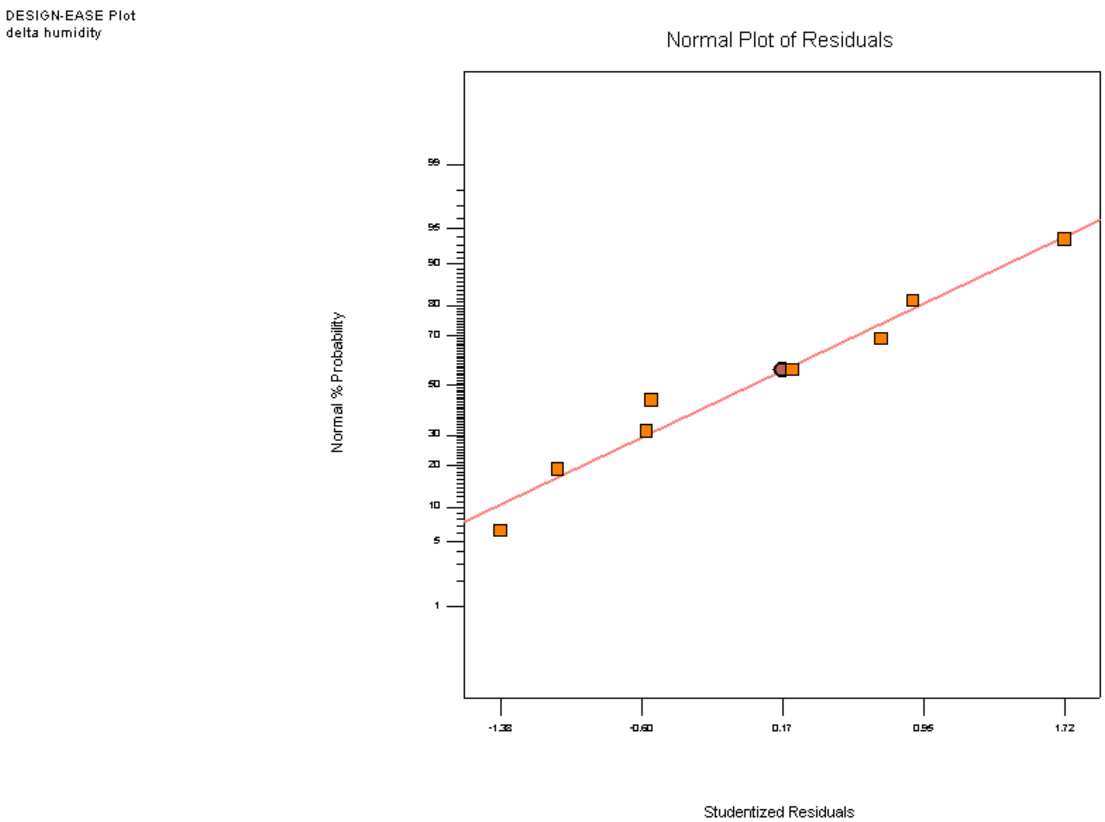
DESIGN-EASE Plot
delta t coil
Lambda
Current = 1
Best = 0.47
Low C.I. = -0.63
High C.I. = 1.61
Recommend transform:
None
(Lambda = 1)
Box-Cox Plot for Power Transforms
Ln(ResidualSS)
Lambda



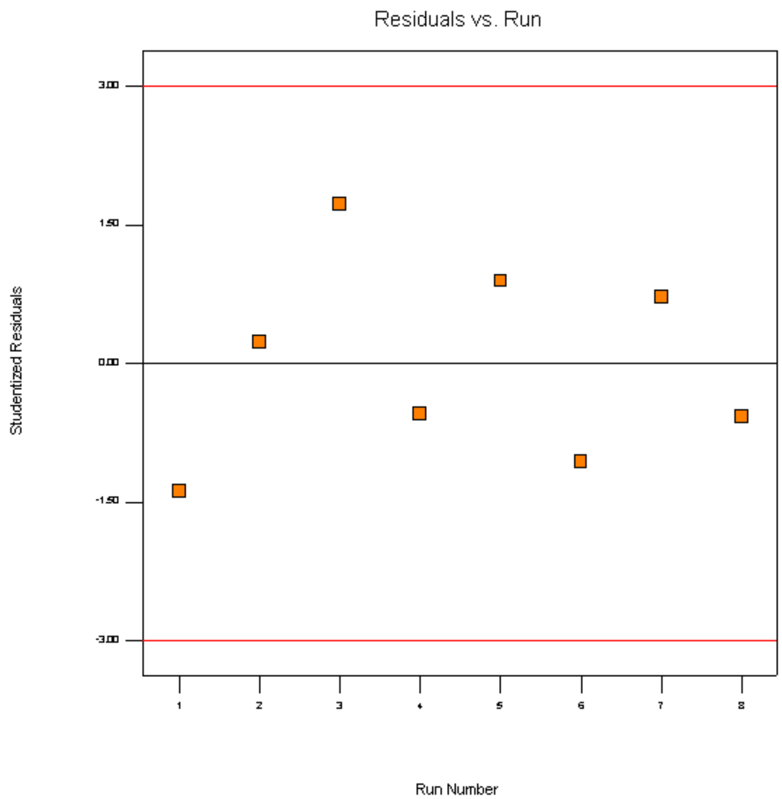
DESIGN-EASE Plot
delta t coil
Normal Plot of Residuals
Normal % Probability
Studentized Residuals



Delta Humidity



DESIGN-EASE Plot
delta humidity



Appendix L. Paper Presented at Second International Conference on Distributed Generation in Stockholm, Sweden

Intelligent Control for Optimal Hybrid Power System
in Commercial Buildings

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Abstract

Distributed energy resources hold great potential for meeting future energy needs. This is especially true when aspects of sustainable development and environmental compatibility are considered. Currently there are many distributed generation (DG) sources in operation, primarily for standby or emergency purposes. DG devices tend to have higher proportionate capital costs and lower efficiencies when compared to central stations for the production of electricity. However, when operated in an optimized combined heat and power (CHP) mode these devices provide many operational and economic advantages over conventional energy supply options. This paper describes CHP applications at two commercial buildings and NiSource Energy Technologies, Inc. efforts to optimize the system operation and maximize the benefits of DG through advanced control systems incorporating artificial intelligence.

Introduction

The term distributed generation (DG) refers to a modular electric generation or storage located at or near the point of use and is meant to distinguish between locally produced power and that produced at a large, central plant [1-2]. In other words, DG is the utilization of an on-site power source to provide electricity and other energy to one or more buildings or facilities [3]. Distributed generation can utilize a wide range of power generators including: biomass-based generators; combustion turbines; concentrating solar power and photovoltaic systems; fuel cells; wind turbines; microturbines; diesel generator sets; hybrid systems and electrical power storage [2]. These alternative sources can produce electric power that range from 5 kW to 50 MW [4] and either be grid connected or operate independent of the grid (stand-alone).

Distributed generation benefits both the utility and the end user. For the utility, distributed generation can help to avoid concerns about spinning reserve margins and transmission and distribution upgrades and under certain conditions can provide voltage support and distribution network stability [3]. Benefits to the customer or end-user include improved power quality and reliability, peak shaving, choice, and potentially lower energy costs.

Combined heat and power (CHP) systems as DG hold the promise of providing electric power as well as economic, operational, and environmental benefits. CHP systems located at the customer's facility generate electricity and can more than double the efficiency of energy utilization by making use of excess heat from combustion. Heat can be utilized for thermal equipment, such as: heat exchangers, active/passive thermal storage or heating ventilating and air conditioning (HVAC) systems. By using CHP, customers also lower greenhouse gas emissions and reduce energy costs.

Today there are many distributed generators in operation. Often these are for stand-by and emergency purposes in hospitals and other applications where electric reliability is critical. Generally these devices are not included in the base load. NiSource Energy Technologies, Inc. (NET) is developing methods to make base-loaded DG operation more feasible. NET is using CHP systems to model and develop a control method optimizing both electric and thermal power using intelligent control techniques. This is crucial for CHP systems, as NET analysis indicates the system must at least double the efficiency of an electric-only application to achieve significant market penetration. Intelligent control techniques permit the HVAC and Distributed Generation systems to control and regulate the supply of the input energy based on the desired outputs.

This paper presents the preliminary results of NET's research on CHP systems installed in two different commercial buildings. One system is in a grid-connected building with the capability for bumpless transition of critical loads to CHP on loss of grid power. It has an aggregated combined heat and power system with dynamic optimization and control to identify performance and both active and passive thermal storages. The second building is an operating hotel. NET is working to understand issues and develop new concepts, including dynamic energy optimization, to develop a CHP package for the hotel industry.

System Description

For the past four years NET has operated a CHP system at a commercial business in Chesterton, Indiana USA. This system has provided a test bed for developing schemes to increase the net energy utilization of a CHP system. The system consists of a 28 KW microturbine, heat recovery and desiccant dehumidification systems and associated controls and optimization functions. A major concern for this application is the cost associated with the operation of the system in comparison with grid power and conventional natural gas heating. The total efficiency of the system is measured based upon the usable energy provided to the building after all losses, including piping, compression, and pumping, are taken into account. The building is modeled through the combination of physical understanding and on-line mathematical system identification in the form of differential equations. Dynamic optimization is performed on the application of the combined heat and power unit and the active/passive thermal storage operation. Due to the uncertainties associated with building systems, e.g. occupancy and weather condition, a three-level hierarchical control system is being developed for this research project.

Figure 1 illustrates the energy utilization for the system at different times during the month of January 2002 for non-optimized operation of the CHP system. The maximum energy utilization for the system was 73% and the typical utilization was less than the maximum. This is attributable to variations in atmospheric temperature as well as various operating conditions.

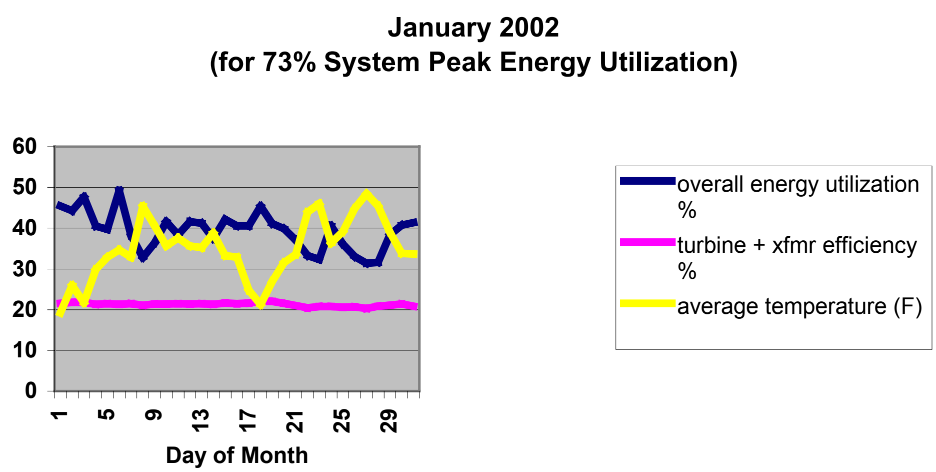

Figure 1: Energy Utilization Percentage

As Figure 1 illustrates, simply utilizing waste heat from a distributed generator to displace space heating does not capture the maximum benefit. NET has been developing schemes incorporating intelligent controls to optimize the energy utilization and thereby increase the benefit and potential of CHP systems. One approach is to optimize the various energy streams for the building. Figure 2 illustrates a typical profile for energy use by a commercial building with heavy nighttime parking lot lighting load located in Northern Indiana with a CHP system installed.

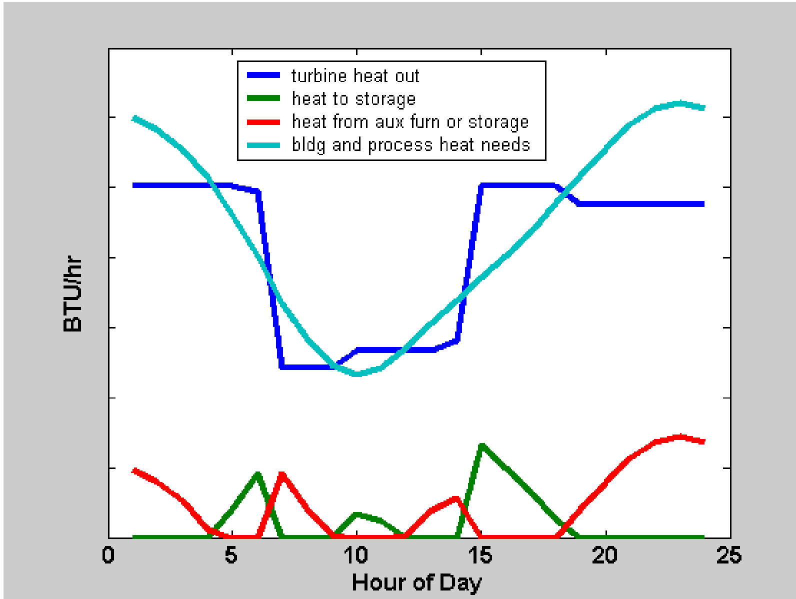

Figure 2: Commercial Building Energy Streams

As can be seen in Figure 2, periodically there is a mismatch between the need for electric energy and the amount of heat produced as a result of the electric generation from a CHP system. NET developed various operating practices, equipment designs, energy storage methods and optimization schemes to better match the energy needs with the particular form of energy available (either heat or electricity).

Since the capital costs of installing equipment can greatly influence system viability, a variety of different approaches have been attempted to improve energy utilization. Learning from the first commercial site has now been extended at the second site, a hotel test site, with the intent of developing a standard CHP package for the hotel industry. One approach is to integrate the operation of the energy system with the operating practices of the building as well as potentially its design. Typically 30-40% of the total energy utilized in a hotel is for water heating. Such use lends itself to a CHP application. Also, most of the smaller hotels are built with standardized designs.

Figure 3 is picture of the hotel test site located in Chesterton, Indiana, where the N.E.T. CHP system, together with passive and active thermal storage, has been installed.

Figure 3: Hotel Test Site

Three microturbines and associated heat recovery equipment are located in a small building behind the hotel (Figure 4). NET anticipates adding other energy sources, including a reciprocating engine, fuel cell, and solar cells This will provide an opportunity to consider the interaction between various electric sources as well as their relative strengths and weaknesses in this operating environment.

Figure 4: CHP Test System Building

The current microturbines supply roughly one third of the electric requirements for the hotel. In addition, heat from the system provides hot water for the laundry, guest rooms, swimming pool, and spa. Current NET research with desiccant dehumidification and absorption cooling at other sites will be considered. A major issue is to use the heat from combustion to provide the maximum benefit. Since the use and occupancy of the hotel changes on an ongoing basis, it was necessary to design an energy management system to respond to changes in use and occupancy patterns. The testing and analytic capabilities at the current facility were designed to allow for the development of equipment and operating schemes that will provide such benefit.

Seventeen hydronic heating zones were installed in the lobby, office, and meeting room areas and three more were installed in the swimming pool area. NET is developing schemes to optimize heating these zones along with heating water for the laundry, rooms, swimming pool, and spa, to maximize the overall energy utilization of the system. Energy concerns for this building are similar to those illustrated in Figure 1, with the added complexity of continually changing occupancy and use patterns for the various regions of the building. Figure 5 illustrates the control manifold for the first group of hydronic heating zones. This manifold is remotely controlled to dynamically control the flow of heat in various regions of the building.

Figure 5: Control Manifold

One part of the attempt to improve the utilization of energy has concentrated on methods to optimize the building system. Given the dynamic nature of the occupancy and energy usage patterns for the building, an intelligent control system is being developed. This type of controller should have a certain degree of autonomy in terms of configuring, reasoning, planning, and making decisions regarding the optimization of the total energy usage.

Technical Approach

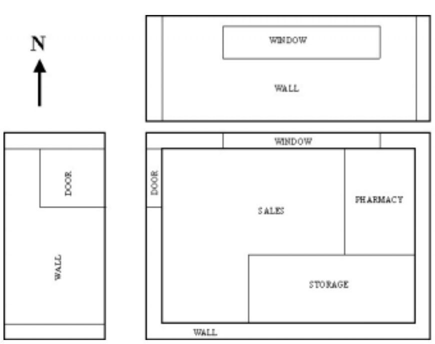

Figure 6: Building Layout

System Modeling

Initially, NET selected a generic supermarket as an example of commercial buildings. Figure 6 depicts the building layout. The supermarket is divided into three zones: (i) Sales, (ii) Pharmacy, and (iii) Storage. To establish a basis for modeling the building, the heat transfer mechanisms and related temperature readings are assessed at every zone in the building. The thermal system model begins with recognizing the thermal source or heat that will be the input of the system.

These thermal sources affect each zone of the building by a combination of different heat transfer mechanisms, such as radiation, convection, and conduction. The thermal dynamics in this model are governed by the conservation of thermal energy, equation 1 below:

$$Q_{in} + Q_g - Q_{out} = \frac{dQ_{st}}{dt} \qquad (1)$$

For the thermal model, heat of Q_{in} can be supplied by the temperature differential between zones as well as radiation from the environment. Heat of Q_g represents the auxiliary heat generated in the zone for heating or cooling purposes. Heat of Q_{out} can come from the temperature difference between the zone temperature and the temperature in the other zone that has lower temperature. The building has several zones, so a set of modules represents each zone in a building , structured by an input-output set to form a transfer function. Through equation (1) a second order transfer function of each zone can be derived. The general structure of the transfer function of each zone would have the composition shown in equation (2):

$$T_{zi}(s) = \left(\sum_j \frac{K_{zi}K_{wj}}{\tau_{zi}\tau_{wj}S^2 + (\tau_{zi} + \tau_{wj})S + (1 - K_{wi}K_{wj})} T_j \right) + \left(\frac{K_{si}\tau_{wi}S + 1}{\tau_{zi}\tau_{wj}S^2 + (\tau_{zi} + \tau_{wj})S + (1 - K_{wi}K_{wj})} T_S \right) \qquad (2)$$

Equation 2 consists of two types of inputs namely: External Temperature (Tj) and The Zone Supply Temperature (Ts). In this equation, i denotes particular, j denotes the boundary side of the zone, τw and τwj represent the time constants of the zone and the partition, while the Kw and Kz represent the heat gain of the zone and the partition as well. In order to identify these parameters, system identification techniques are applied by utilizing the obtained measured data of the model input-output.

System Optimization

In order to control the DG system successfully, real-time control approaches that can integrate information from building loads, generator and the grid are required. This information is used to produce the optimal set point for the generator and the HVAC system in the building. There may be trade-offs between the cost of gas and the cost of grid electricity. All these issues should be considered in the energy utilization optimization process.

Distributed Generation Operation Optimization

Ideally, the control algorithm that is applied to operate DG would reduce the operating cost over the life of the equipment to minimize the cost to the building operator [1]. It is necessary to compare the cost of grid electricity and locally produced electricity at each hour (or other appropriate time interval) as well as the cost of fuel consumption, e.g. gas, and locally produced heat. Energy supply is optimized based upon the maximum benefit from the available source options. To determine if the generators should operate, the total electricity cost (C_{ELEC}) and the total gas cost (C_{GAS}) should be evaluated. Furthermore, the optimization must be able to keep track of all data acquired during a given billing period and provide cost estimates for the current hour. At each hour of the billing period, the optimization model determines the number of generators that should run for that hour and their set points. To maximize the system benefits, the model predicts the building load data for that hour, including such factors as : whole building kWh use, whole building Btu use, kWh used for domestic water heating, Btu used for domestic water heating, kWh used for space heating, Btu used for space heating and kWh used for space cooling.

For this model, the cost function in this case includes the cost of providing on-site electrical (ϕ_{KW}) and thermal energy by the distributed generators (ϕ_{GAS}), which are compared with the grid consumption (ϕ_{KWH})to choose the lowest cost option. The algorithm should also account for any utility incentives (ϕ_{CRED}) and the variable operation and maintenance ($\phi_{O\&M}$) costs during the operation [4]. Positive cash flow based on any utility incentives include transmission loss credit, wheeling charge credits, voltage support credits, etc. Equation (3) describes a cost matrix representing all reasonable combinations of generation available to a building. The combination with the lowest cost is chosen and implemented.

$$\begin{aligned}C_{ELEC} &= \phi_{KWH}\begin{bmatrix} kWh_{BLDG}(1)-kWh_{GEN}(1) \\ kWh_{BLDG}(2)-kWh_{GEN}(2) \\ \dots \\ kWh_{BLDG}(k)-kWh_{GEN}(k)\end{bmatrix} + \phi_{KW}\begin{bmatrix} kW_{BLDG}(1)-kW_{GEN}(1) \\ kW_{BLDG}(2)-kW_{GEN}(2) \\ \dots \\ kW_{BLDG}(k)-kW_{GEN}(k)\end{bmatrix} + \dots \\ &\dots\dots\dots\dots + \phi_{GAS}\begin{bmatrix} Btu_{BLDG}(1)-Btu_{GEN}(1) \\ Btu_{BLDG}(2)-Btu_{GEN}(2) \\ \dots \\ Btu_{BLDG}(k)-Btu_{GEN}(k)\end{bmatrix} + \dots \\ &\dots\dots\dots\dots + \phi_{CRED}\left[\sum kWh_{GEN}\right] + \phi_{O\&M}\left[kW_{INST} + \sum kWh_{GEN}\right]\end{aligned} \tag{3}$$

Passive Thermal Storage Operation Optimization

In buildings incorporating passive solar heating buildings the energy storage is often coupled to the living and/or working spaces. Therefore, the discharge from storage is determined by the governing heat-transfer equation and cannot be switched on or off. The operation of a passive energy storage system requires an energy management strategy, which depends on the characteristics of the system equations [1]. An effective control strategy for energy movement must allow for the time delay between energy input and release. Several control strategies can be developed to satisfy basic requirements such as minimum cost and/or comfort.

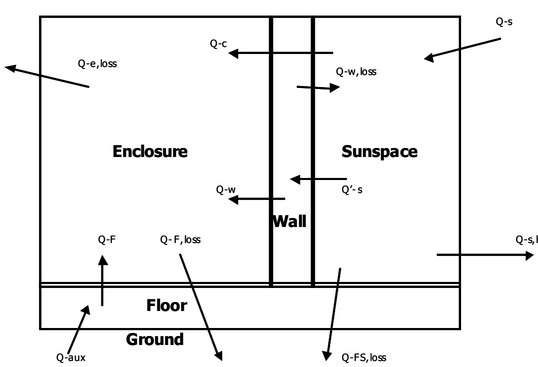

Figure 7: Trombe Wall Passive Storage

In the supermarket examples, the sunspace, the storage wall, the enclosure and the storage floor are modeled using a single node for each region (i.e. lumped capacitance). The collector-storage wall operates as a passive component by transmitting a portion of the absorbed solar energy into the building via either of the two paths. The first path, energy is conducted through the wall and subsequently convected and radiated from the inside wall surface into the building. The second path is convection of energy from the outer wall surface to the air in the gap between the wall and the innermost glazing. This air is circulated through the gap, heated and returned to the building. This model will be used to develop and analyze the minimum cost control strategy.

The optimal use of auxiliary heat input can be determined using a dynamic optimization technique [1,6,7,8]. The technique used in this effort is the maximum principle. The statement of what is to be optimized is described by a quadratic objective function shown in equation (4),

$$J = \int_{to}^{tf} [fQ_{aux}^2 + C1(T_e - T_{set})^2 + C2(H_e - H_{set})^2] dt \qquad (4)$$

where f is the utility rate structure, C1 is a comfort weighting-coefficient for temperature, C2 is a comfort weighting-coefficient for humidity, Tset is the desired temperature (^{0}C), He is enclosure Humidity (%RH) and Hset is the desired Humidity (%RH). The first term represents a measure of energy cost and the other two terms are measures of discomfort. As an approximation, the objective function is minimized on a daily basis and the enclosure temperature is forced to equal the desired temperature at midnight. The maximum principle by using the Hamiltonian is proposed to minimize J and to derive the optimum set point for the auxiliary Heat (Qaux) that needs to be supplied to the zone.

Three-Level Hierarchical Control System

The intelligent control system was defined as a control system that has definitive degree of autonomy, which is utilized for self-learning, self-reconfigurability, reasoning, planning and decision-making, and extracting the most valuable information from unstructured and noisy data from a dynamically complex system and/or environment [10]. In order to have these features, an intelligent control system tends to have a hierarchical structure [5]. Such structure is called "Three-Level Hierarchical Control". Three-level hierarchical control system is divided into three components: supervisor, coordinator and local controllers. Intelligent control adds supervisor layer and coordinator layer to the local controller layer as an outer loop to augment existing functionality rather than replacing it. Figure 8 illustrates the structure of the three-level hierarchical control system.

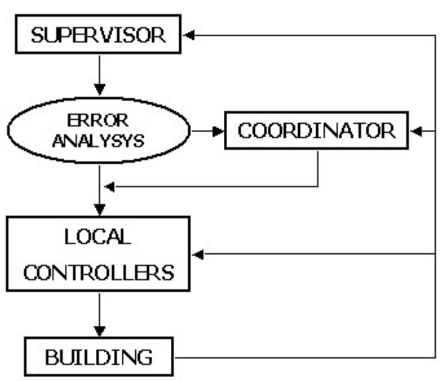

Figure 8: Three-Level Hierarchical Control System

The supervisor is responsible for long-term set point scheduling and optimization for local controller based on accumulated knowledge of past building usage and behavior. The supervisor layer incorporates zone occupancy, utility cost, building dynamics, distributed generation dynamics and weather forecast as its inputs. Learning process that is performed independently by the supervisor layer and past building dynamics will be result in signatures that would reside inside the supervisor database. Subsequently, the supervisor maps these signatures onto desired set points representing the needs for heating and cooling of the building, and for the output power of the distributed generation. The integrated supervisor will automatically provide the local controller with the set points schedule in advanced, associated with the current input and disturbance conditions that matched with the supervisor database. At the same time, the supervisor will continue to do the learning process from the new input patterns that were captured by the sensors during the operation. The supervisor autonomously optimizes the existing input patterns with respect to a performance index penalizing the energy consumption, occupant discomfort and model error.

The coordinator is responsible to provide short-term error correction between the supervisor and the local controllers when unexpected inputs or disturbances take place. For example, during late night in the winter the supervisor layer provides local controller with set point where there is no need to turn on the heater since the occupancy is assumed to be zero. However when occupancy suddenly changed during that period of time, the building has to provide comfort to the zone by turning on the heater or changing the temperature set points. This is the time when the coordinator layer becomes active. The coordinator modifies the supervisor schedule so that the local controller will correct its set points in order to provide comfort to the zone. The coordinator error correction procedure consists of a rule-base relating the set points error with the right set point correction. The coordinator has primary inputs of instantaneous motion sensor outputs, supervisor outputs, a base temperature schedule from the supervisor database, and current zone set points. The local controller layer is responsible for providing a robust control loop to maintain system set points with respect to time-varying inputs and disturbances in the short-term. This type of controller consists of adaptive loops for every zone in the building. Inputs in the form of set points, produced by the supervisor and coordinator, are supplied to local controllers to be activated for specific zones in the building.

Simulation Results

Simulations are performed in order to study the building response due to environmental varieties. This simulation includes the system identification process, where the building thermal properties and parameters would be acquired. The second order system model was derived from the physics of the building thermal response, which incorporates the envelope of the zone. For the supermarket example, all of the envelop elements such as walls, windows, roof and floor are aggregated into one element called ‘wall.’ Figure 9 depicts the layout of the second order system model. Based on the available measurement data at the supermarket, the zone of interest, which is the sales area, has two temperature inputs, Ta, which is the ambient temperature, and Ts, which is the supply temperature from the air-handling unit. The output of the simulation is the zone temperature Tz. Figure 9 and 10 present the input data of the system, which consists of ambient temperature (Ta) and supply temperature (Ts).

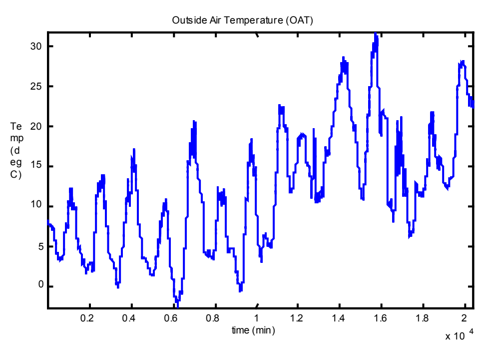

Figure 9: Ambient Temperature Input

Equation (5) and (6) are the two transfer functions that were generated based on the least square error minimization in system identification. Equation (5) is the transfer function for Ta input while equation (6) is for the Ts input. Subsequently, the obtained model is subjected to the input data of Ta and Ts to validate the model. The simulation output is then compared against the measured output data.

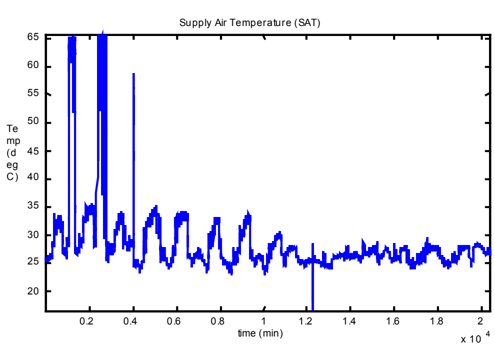

Figure 10: Supply Temperature Input

$$\frac{Tz}{Ta}=\frac{417.3\times10^{-6}}{46S^2+499S+1.004} \qquad (5)$$

$$\frac{Tz}{Ts}=\frac{(-8.0886)S-0.0663}{46S^2+499S+1.004} \qquad (6)$$

Figure 11 shows the simulation result of the second order system. The solid line is the simulation result, while the dashed line is the measured data. The obtained second order system model is able to capture and emulate the temperature variation and the dynamic of the output data. The least square error of this model is 0.5^0C. Based on this result, it is certain that the second order system will be applied to model each zone in a building system.

The obtained model allows us to identify the time constants of building envelope and the zone. The time constant of the building envelope is 6 hours, while the time constant of the zone of interest is 2 hours. This data will be incorporated as the knowledge for the development of fuzzy model.
As part of the energy optimization strategy, which incorporates both passive and active elements, wall time constant will play an important role. This is especially true in the case of having trombe wall. Figure 12 shows the heat energy stored in different type of wall time constant during one-day period. As shown, the proposed energy optimization technique will require online knowledge of storage time constant.

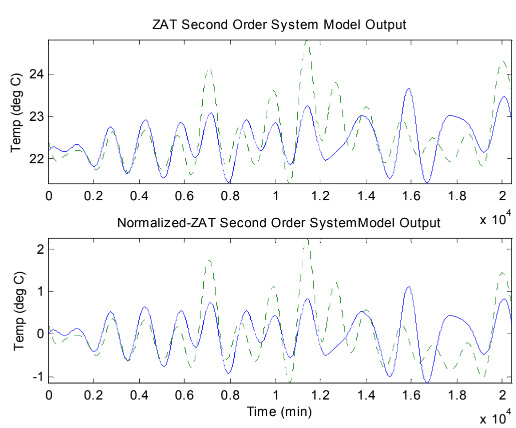

Figure 11: Building Temperature

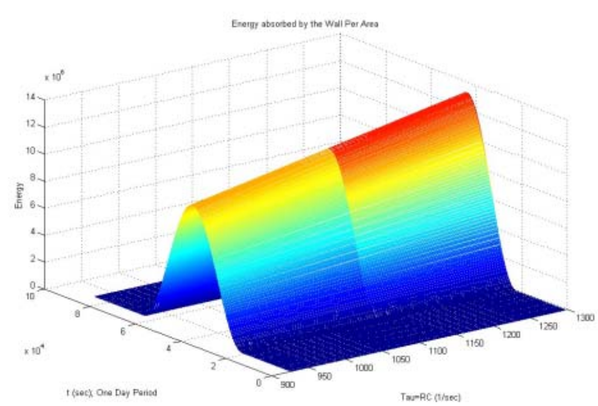

Figure 12: Different Wall Time Constant

Conclusion

This paper presents a new strategy for the integrated applications of distributed generation, HVAC system, active/passive thermal storage and electrical grid interconnection for a building system. Although this research project is still under development, this paper has been able to describe the elements that need be incorporated into an intelligent building system from the energy usage point of view. Two commercial building sites have been equipped with CHP units and formed test-beds for the NET DG-based energy optimization analysis.

A three-level hierarchical control system for the integration of distribution generation, HVAC and thermal storage provides benefits in terms of:

- Integration of utility rate structures and other relevant information databases into the control strategy
- Improved optimization of comfort/energy usage
- Operational simplicity for the end-user
- Reduction in the equipment capacity required
- The ability to shed load from unoccupied zones when demand cannot be met

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References

[1] G.C. Bakos, "Improved energy management method for auxiliary electrical energy saving in a passive-solar-heated residence", Energy and Buildings 34 (2002) 699-703
[2] National Renewable Energy Laboratory, Distributed Power Program, http://www.eren.doe.gov/distributedpower (2002)
[3] Mike Scott, "Distributed Generation", Energy-Tech, July (2002) 6-16
[4] Curtis, Peter S, "Control of distributed electrical generation system", ASHRAE Transactions, v106 (2000) 661-668
[5] Shoureshi, R; Brckney, L; DeRoo, B, "Fuzzy-based energy management system for large buildings", American Society of Mechanical Engineers, Dynamic Systems and Control Division, v58 (1996) 797-804
[6] R.C. Winn, C.B, "Optimal control of auxiliary heating of passive-solar-heated buildings", Solar Energy 35 (1985) 419-427

[7] J.F. Kreider, C.J Hoogendoorm, F. Kreith, “Solar Design-Components, Systems, Economics”, Hemisphere Pub, USA, 1989
[8] L.S. Pontrayagin, V.G. Boltyanskii, R.V. Gamkrelidze, E.F. Mischenko, “The mathematical theory of optimal processes”, Interscience Publisher, New York 1962.
[9] D.M. Utzinger, S.A. Klein, J.W. Mitchell, “The effect of air flow rate in collector-storage walls”, Solar Energy 25 (1980) 511-519
[10] Shoureshi, R. “Intelligent Control System: Are they for real?”, Transsactions of the ASME Journal Dynamic Systems, Measurement, and Control, June (1992)

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13. ABSTRACT *(Maximum 200 words)* This report describes NiSource Energy Technologies Inc.'s second year of a planned 3-year effort to advance distributed power development, deployment, and integration. Its long-term goal is to design ways to extend distributed generation into the physical design and controls of buildings. NET worked to meet this goal through advances in the implementation and control of combined heat and power systems in end-user environments and a further understanding of electric interconnection and siting issues. The specific objective of work under this subcontract is to identify the system integration and implementation issues of DG and develop and test potential solutions. In addition, recommendations are made to resolve identified issues that may hinder or slow the integration of integrated energy systems into the national energy picture.			
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